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**DRAFT**

**DERIVATION OF TARGET  
CLEAN-UP LEVELS FOR  
SOILS AT THE SOLAR  
EVAPORATION PONDS**

**ROCKY FLATS PLANT**

**U.S. DEPARTMENT OF ENERGY  
ROCKY FLATS PLANT  
GOLDEN, COLORADO**

**ENVIRONMENTAL RESTORATION PROGRAM**

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## EXECUTIVE SUMMARY

This report presents an approach to deriving target clean-up levels for chemotoxic contaminants in soils at the Solar Evaporation Ponds at the Rocky Flats Plant. The results of this assessment will be used to evaluate and select the manner in which contaminated soils will be managed during closure of the ponds under RCRA. The general approach involves four basic steps: the identification of site contaminants, an exposure assessment, a toxicity assessment, and the determination of clean-up levels.

Sampling data from all media which may have become contaminated through prior disposal activities at the site were reviewed to identify potential site contaminants. The 58 chemicals reported in these samples were screened to select the site contaminants for which clean-up levels would be derived. Those inorganics and chemotoxic radionuclides that were reported in solar pond soil samples above background concentrations, and all organic compounds that were reported in site-associated media were considered to be site contaminants. A total of 35 site contaminants were identified.

The clean-up levels were derived based on a hypothetical future scenario, that of an individual who lives at the site for a 70-year lifetime. The resident is assumed to be exposed to site contaminants through five exposure routes: incidental soil ingestion, vegetable ingestion, dermal contact with soil, the inhalation of airborne contaminated soil, and the inhalation of vapors.

Initially, clean-up levels were determined based on the assumption that all 35 site contaminants could be present at a given location. Target soil concentrations were derived for both the noncarcinogenic and carcinogenic site contaminants based on noncarcinogenic risk, using a clean-up goal of a hazard index

of one, and for the carcinogenic site contaminants based on a goal of a one in one million ( $10^{-6}$ ) lifetime total cancer risk. The lowest clean-up concentration calculated for each carcinogen was chosen as the final target clean-up concentration for the chemical. The approach to deriving clean-up levels involves the determination of risk-based soil concentrations for each contaminant for each of the five potential exposure routes. The exposure route-specific soil concentrations are then used to derive risk-based clean-up levels for all exposure routes combined.

Because it is unlikely that all 35 site contaminants are present throughout the soils beneath and surrounding the solar ponds, an approach to deriving location-specific clean-up levels is presented. The approach involves a modification of the clean-up levels that were derived based on all 35 site contaminants, adjusting for the number of contaminants at a given location. Other factors which could affect clean-up levels at a given location are also discussed.



## DERIVATION OF TARGET CLEAN-UP LEVELS FOR SOILS AT THE SOLAR EVAPORATION PONDS

### SECTION 1.0

#### INTRODUCTION

##### 1.1 BACKGROUND

To support the development and evaluation of remedial alternatives for contaminated soils at the Solar Evaporation Ponds at the Rocky Flats Plant, remediation criteria (target clean-up levels) were derived for nonradiological contaminants in the soil that may pose potential human health risks.

The July 1, 1988 closure plan assumes closure of the ponds as a landfill utilizing a cap to cover contaminated soil areas. The extent of the cap was determined by the completed site characterization study presented in Appendix 6 of the closure plan (DOE, 1988). Closing the solar ponds as a landfill with contaminated soil results in a unit which will require long-term institutional controls at the source area. These controls would be required after the groundwater corrective action is complete. A remedial action for the solar pond area soils, such as removal, would allow for a "clean" closure of the source and, therefore, would eliminate the need for capping and long-term controls required for "dirty" closure. However, pursuant to RCRA closure regulations for surface impoundments [40 CFR (Code of Federal Regulations) 264.228(a) (1)], all contaminated soils would have to be removed. This may prove to be impractical at the solar ponds.

In order to make the closure consistent with remediation of CERCLA sites at the Rocky Flats Plant, it is proposed that the

closure performance standards for the soil remedial action be established by a risk-based process, which is discussed herein. The risk-based process would be conducted to establish allowable soil concentrations that are protective of human health through all plausible routes of human exposure. Soil remedial actions for closure of the solar pond source areas would be targeted at achieving these risk-based closure performance standards. This approach is also consistent with the closure performance standard presented in 40 CFR 264.111(b), which states that closure must minimize or eliminate, to the extent necessary to protect human health and the environment, any post-closure escape of hazardous constituents.

Section 121 of CERCLA, as amended by SARA, requires that remedial actions of Superfund sites comply with applicable or relevant and appropriate requirements (ARARs) of Federal laws and more stringent, promulgated state laws. No Federal soil ARARs are available, nor have any soil clean-up objectives been established by the Colorado Department of Health. Consequently, remediation criteria or target clean-up levels were derived using risk-based techniques.

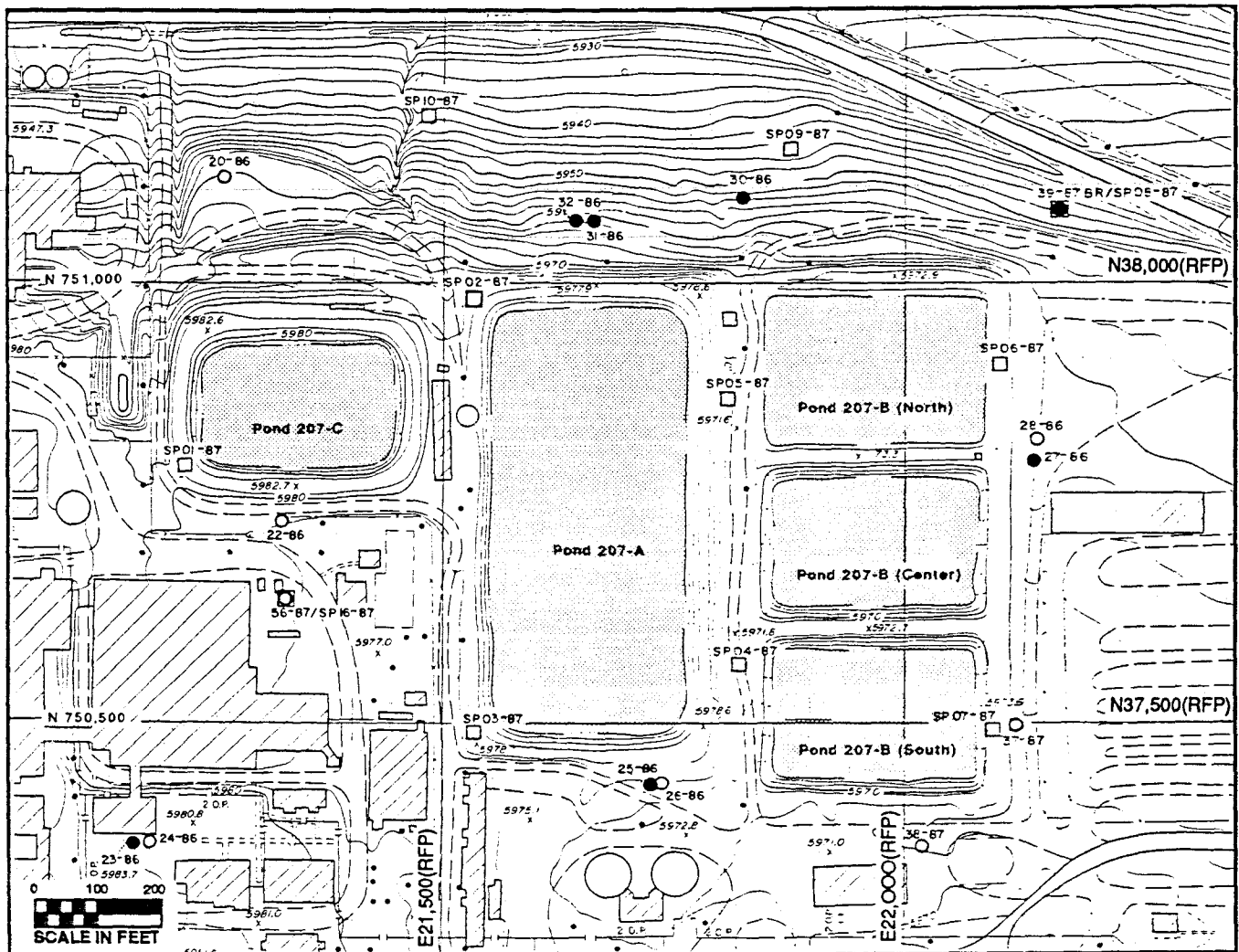
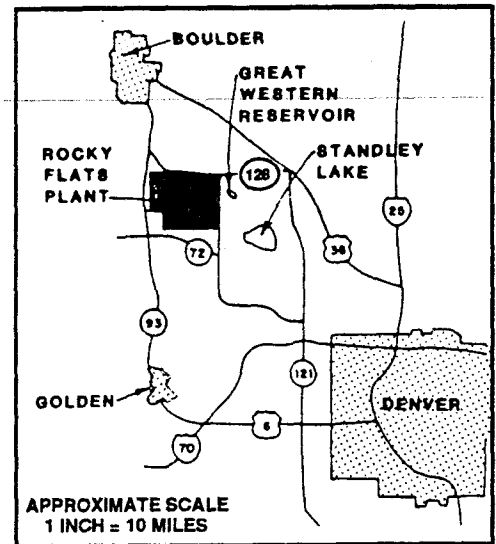
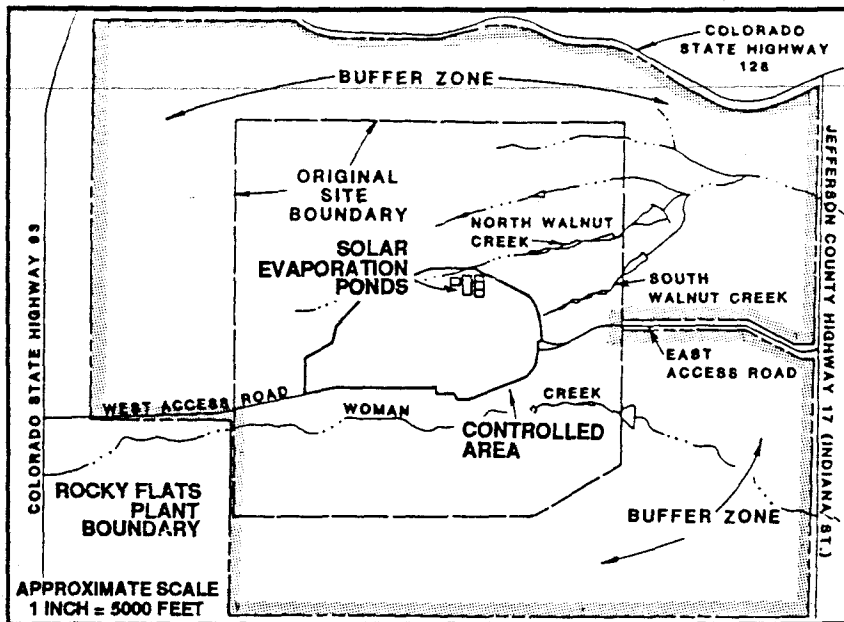
The approach proposed herein to establish clean-up levels attempts to provide an organized and technically defensible process for establishing clean-up levels in soil which will ensure that potential receptors are afforded an acceptable level of protection. The Solar Pond Closure Plan, dated July 1, 1988, could be modified to include the recommendations of this risk-based assessment, with the existing capping alternative reserved as the contingency plan for closure in the event that further evaluations indicate that closure without a cap is not possible or practical.

## 1.2 SITE DESCRIPTION AND HISTORY

The Rocky Flats Plant is located in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver (Figure 1-1). Major buildings are located within the plant security area of approximately 400 acres. The security area is surrounded by a buffer zone of approximately 6,150 acres. This report addresses the solar evaporation ponds which are located on the north side of the perimeter security zone (PSZ) at the Rocky Flats Plant. There are three solar evaporation ponds designated as 207-A, 207-B, (divided into north, center, and south sections), and 207-C (Figure 1-1).

The original solar evaporation pond consisted of a single clay-lined impoundment constructed in December 1953 in the vicinity of the existing Pond 207-C. The clay-lined pond had two containments measuring 100 by 200 feet and 200 by 200 feet, respectively, and was operated with both one and two cells until 1956 when its regular use was discontinued. However, at least one of the two cells held liquids at least once since 1963. This pond was removed in 1970 when existing Pond 207-C was constructed.

Pond 207-A was placed in service in August 1956. The pond was originally lined with asphalt planking approximately one-half inch thick. Ponds 207-B North, Center, and South were placed in service in June 1960. These ponds were also lined with asphalt planking. Pond 207-C was placed in service in December 1970. The original lining is presumed to be the existing lining. Modifications to the ponds' linings have been made since the original construction because of cracking and slumping of the existing linings and leakage of the pond contents. Pond 207-A and the three 207-B ponds have been relined at least one time each. No records were located which indicated that Pond 207-C has been relined (DOE, 1988).



# ROCKY FLATS PLANT GOLDEN, COLORADO

FIGURE 1-1  
LOCATION MAP OF THE SOLAR EVAPORATION PONDS

During their period of operation, the solar evaporation ponds have received high nitrate, low-level radioactive process waste, and treated aluminum hydroxide waste. In addition, the solar evaporation ponds have received sanitary sewage sludge, lithium metal, sodium nitrate, ferric chloride, lithium chloride, sulfuric acid, ammonium persulfate, hydrochloric acid, nitric acid, hexavalent chromium, and cyanide solutions. To the extent possible, oils and solvents were not sent to the ponds so that surface scum would not hamper evaporation (DOE, 1987).

### 1.3 GENERAL APPROACH

The approach to the derivation of target clean-up levels for soils at the solar evaporation ponds consists of four main steps. These steps are briefly described below.

#### Identification of Site Contaminants

Recent sampling data are reviewed for all media which may have been impacted by contaminants from the solar evaporation ponds and potential site-associated chemicals are identified. The concentrations of chemicals reported in solar pond soils are compared with background concentrations. All potentially toxic chemicals which were reported above background and/or whose presence may otherwise be associated with previous disposal activities at the ponds are considered to be site contaminants.

#### Exposure Assessment

An exposure scenario is created which characterizes potential human receptors. Possible routes of exposure to contaminants are identified for these receptors.



## Toxicity Assessment

Available U.S. EPA toxicity values (reference doses and carcinogenic potency factors) are identified for the site contaminants. Toxicity values are derived for chemicals when such values are unavailable.

## Determination of Clean-Up Levels

Soil clean-up levels are derived based on the potential exposure routes identified in the Exposure Assessment and the toxicity values identified in the Toxicity Assessment. Clean-up levels are developed based on both carcinogenic and noncarcinogenic health effects taking into account the possible additive toxic effects of the site contaminants.

The following sections (Sections 2 through 5) address these four steps, respectively.

## SECTION 2.0

## IDENTIFICATION OF SITE CONTAMINANTS

In this evaluation, all chemicals which may have been associated with previous disposal activities at the solar evaporation ponds and are associated with potential nonradiologic toxic effects are considered to be site contaminants. Although final target clean-up levels are not being determined for radionuclides at this time, the noncarcinogenic toxic properties of the radionuclides were considered in determining clean-up levels for the other nonradiological contaminants.

Because soil and groundwater samples could not be collected directly under the ponds, sampling data collected during 1987-1989 from media which may have been impacted by chemicals disposed in the ponds were reviewed to determine the potential site-associated chemicals (U.S. DOE, 1988; Volume 2, this document). The sampled media included sludge and sediments from the ponds, soil from the berms surrounding the ponds, and downgradient groundwater. The 58 chemicals that were identified in these samples are listed in Table 2-1.

Because this evaluation is concerned with determining soil clean-up levels for site-related contaminants only, the reported chemicals were screened to determine which chemicals may have been present as a result of previous disposal activities at the site. It was conservatively assumed that all of the organics reported in site-associated samples were site contaminants, even if they were not detected in soil samples collected around the ponds. Only five organic compounds (acetone, bis(2-ethylhexyl)phthalate, 2-butanone, ethylbenzene, methylene chloride, and toluene) were reported in samples from the soils surrounding the solar ponds. All but ethylbenzene and toluene were also reported in blanks. Because it is possible that the organics that were reported in site-related media (e.g., down-

Table 2-1

Chemicals Reported in Soil, Sludge, Sediment, and/or Ground-water Samples Associated with the Solar Evaporation Ponds

<u>Organics</u>	<u>Inorganics</u> <sup>1</sup>
Acetone	Aluminum
Bis(2-ethylhexyl)phthalate	Antimony
2-Butanone	Arsenic
Carbon tetrachloride	Barium
Chloroform	Beryllium
1,1-Dichloroethane	Bicarbonate
1,2-Dichloroethane	Cadmium
1,1-Dichloroethene	Calcium
Ethylbenzene	Chloride
Methylene chloride	Chromium
Tetrachloroethene	Cobalt
Toluene	Copper
1,1,1-Trichloroethane	Cyanide
1,2-Trichloroethane	Iron
Trichloroethene	Lead
Vinyl chloride	Lithium
	Magnesium
	Manganese
	Mercury
	Molybdenum
	Nickel
	Nitrate-Nitrite (as N)
	Phosphate
	Potassium
	Selenium
	Silver
	Sodium
	Sulfate
	Sulfide
	Thallium
	Vanadium
	Zinc
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Radium 226	
Radium 228	
Strontium 89, 90	
Tritium	
Uranium 233, 234	
Uranium 235	
Uranium 238	

<sup>1</sup> The inorganics were assayed for as "total." Specific chemical species were not identified.

gradient groundwater) may be present beneath the ponds, and because there were no background soils data available for organics, all of the reported organic compounds were considered to be site contaminants.

The inorganics, which naturally occur in the environment, and the radionuclides, were screened further. Only the inorganics and radionuclides that were reported in the soil samples collected around the solar ponds at concentrations that were above background were considered to be site contaminants. On-site and background samples were collected from the four general soil types that are present at the solar pond site: alluvium, colluvium, claystone, and sandstone. The background samples were collected from soils located in the plant buffer zone to the southwest and northeast of the plant. Solar pond soils data were available for all of the inorganics and radionuclides listed in Table 2-1, with the exceptions of bicarbonate, chloride, phosphate, and sulfate. Background soils data were not available for these chemicals or for cyanide. The complete set of soil sampling data, including the data for the inorganics, radionuclides, and organics, is presented in Volume 2 according to soil type. Chemicals were analyzed in accordance with the methodology presented in the quality assurance and control plan for the plant restoration program (Rockwell International, 1989).

To determine which inorganics and radionuclides were above background in solar pond soils, the maximum concentration reported for each chemical in each solar pond soil type was first compared with either the upper limit of the 95 percent tolerance interval or the maximum concentration of the corresponding background soil type samples. It is appropriate to use the upper limit of the 95 percent tolerance interval of the background data for comparison only if a chemical is detected in 50 percent or greater of the background samples. Therefore, if a chemical

was detected in fewer than 50 percent of the background samples, the maximum concentration of the chemical reported in the background samples was used for comparison. The 95 percent tolerance interval represents a statistical range of concentrations that contains 95 percent of the population with 95 percent confidence, based on a normal data distribution. The methodology used to calculate the upper limit of the tolerance interval is described in Appendix A.

If the maximum concentration of a chemical in each soil type were equal to or less than the upper limit of the 95 percent tolerance interval/maximum concentration for the corresponding background samples, the chemical was considered to be within the background range and consequently was eliminated as a site contaminant. The chemicals that were eliminated as a result of this initial comparison with background were cesium, molybdenum, silver, tin, radium 226, radium 228, and sulfide. Because background data were unavailable for cyanide, it was retained as a site contaminant. The background values that were used for comparison are presented for the inorganics and radionuclides by soil type in Appendix B, Tables B-1 through B-12.

Even if two data sets are taken from the same population, it is possible for the maximum concentration of one data set to exceed the upper limit of the 95 percent tolerance interval of the second data set. Therefore, for those chemicals for which the maximum on-site concentration exceeded the upper 95 percent tolerance interval of the background data, other factors were taken into consideration in deciding if the chemicals were above background. These factors, which are presented for the inorganics and radionuclides by soil type in Appendix B, Tables B-1 through B-12, included the number of on-site samples that were above background, the average concentration of the values that were reported above background, and the maximum concentration reported above background. On the basis of an evaluation (i.e., weighing) of these factors, the following chemicals were

also eliminated as site contaminants: aluminum, antimony, cobalt, copper, magnesium, manganese, zinc, and uranium 235.

The chemicals that were considered to be above background in one or more soil types are listed in Appendix B, Table B-14. The chemicals that were eliminated as site contaminants based on a comparison with background are summarized in Table B-13. Table B-13 also presents the specific reason(s) that each of the chemicals was eliminated.

Although judged to be above background, several inorganic chemicals were eliminated from the final list of site contaminants because they are assayed for primarily as general quality indicators, and because they are not, in general, of toxic concern (i.e., their toxicity is very low). These inorganics were calcium, potassium, and sodium. Bicarbonate, chloride, and phosphate, for which there were no soils data, were eliminated from the final list of site contaminants for the same reason. Although iron, nitrate, and sulfate also have a low toxicity, they were considered as site contaminants because they are more toxic than the aforementioned chemicals and because of their site history. Although relatively nontoxic compared with other heavy metals, iron is potentially more toxic than the chemicals that were eliminated based on low toxicity (i.e., calcium, sodium, etc.). Both nitrate and sulfate are sufficiently toxic for their toxic effects to have been the primary basis for developing Maximum Contaminant Levels (MCLs) for drinking water (primary MCL for nitrate, secondary MCL for sulfate). In addition, iron (as ferric chloride), nitrate (as sodium nitrate) and sulfate-containing chemicals (sulfuric acid, ammonium persulfate) were reportedly disposed in the ponds, and could, therefore, be present at levels of concern in the soil beneath the ponds.

Of the radionuclides, only uranium was considered as a site contaminant at this time. As stated in the introduction, this

report does not address clean-up levels for radiologic contaminants based on radiotoxicity. However, the noncarcinogenic health effects of radionuclides (i.e., chemotoxicity) are considered when determining clean-up levels for the nonradiological noncarcinogenic site contaminants. Based on the surveyed literature, of the radionuclides, only uranium has evidence of chemotoxic health effects that are of potential concern, having been associated with chemotoxicity to the kidneys (EPA, 1985a). Data concerning the possible chemotoxic health effects of the other radionuclides that were reported above background are lacking.

Finally, in addition to the organic chemicals detected in sampled media, polycyclic aromatic hydrocarbons (PAHs) were also considered to be site contaminants. PAHs were not reported above detection limits in the soil samples that were collected surrounding the ponds. Nevertheless, because the solar ponds were lined with asphalt and also received sanitary waste, it is possible that some PAHs which are common contaminants of asphalt and sewage, may have leached in to the soil beneath the ponds. Target clean-up levels were, therefore, also determined for PAHs.

The solar pond site contaminants for which soil clean-up concentrations were developed are presented in Table 2-2.

Table 2-2

Solar Pond Site Contaminants

Organics	Inorganics
Acetone	Arsenic
Bis(2-ethylhexyl)phthalate	Barium
2-Butanone	Beryllium
Carbon tetrachloride	Cadmium
Chloroform	Chromium
1,1-Dichloroethane	Cyanide
1,2-Dichloroethene	Iron
1,1-Dichloroethene	Lead
Ethylbenzene	Lithium
Methylene chloride	Mercury
PAHs	Nickel
Tetrachloroethene	Nitrate-Nitrite
Toluene	Selenium
1,1,1-Trichloroethane	Strontium
1,1,2-Trichloroethane	Sulfate
Trichloroethene	Thallium
Vinyl chloride	Vanadium
	Uranium <sup>1</sup>

- <sup>1</sup> Uranium (as total uranium) is listed in the remainder of the report with the nonradiologic inorganics, because only its chemotoxic properties are being considered at this time.



## SECTION 3.0

## EXPOSURE ASSESSMENT

**3.1 HYPOTHETICAL EXPOSURE SCENARIO**

To determine target clean-up levels, a hypothetical exposure scenario was created based on future land use potential. It was assumed that in the future a residential development might be located on, and in the area surrounding, the solar evaporation pond site. This scenario is consistent with previous U.S. EPA and Colorado Department of Health (CDH) guidance regarding an appropriate future use scenario for the Rocky Flats Plant site. Prior to the preparation of a draft risk assessment for the 881 Hillside at the Rocky Flats Plant, a meeting was held on November 9, 1987 at the offices of U.S. EPA-Region VIII between representatives of EPA-Region VIII, CDH, and Rockwell International. The use of a housing development scenario to evaluate potential future human health risks posed by contaminants at the Plant site, was agreed upon by those in attendance. Although this is not necessarily a most probable land use scenario for this site, it is expected to represent a worst case exposure scenario. Therefore, choosing clean-up levels based on a residential scenario would be expected to be protective of potential receptors in other scenarios (e.g., workers in an industrial or commercial setting).

It was assumed that an individual lives at the site over a 70 year lifetime and that exposure to contaminants in the soil potentially occurs on a daily basis through five exposure routes:

- Incidental soil ingestion;
- Ingestion of vegetables grown in contaminated soil;

- Dermal contact with soil;
- Inhalation of airborne contaminated soil; and
- Inhalation of vapors.

These exposure routes are discussed in greater detail in Section 5.0. Exposure to contaminants through groundwater usage was not considered in this evaluation. The reasons for the elimination of this pathway are discussed in the following subsection.

### 3.2 GROUNDWATER PATHWAY

Exposure to contaminants through groundwater usage was not considered in the determination of clean-up levels. The yield from both the shallow and deep aquifers underlying the solar evaporation ponds is expected to be too low for the aquifers to be a practical source of water for residential (or commercial/industrial) use.

The uppermost aquifer at the solar evaporation ponds is defined in Section E of the Rocky Flats Plant Post-Closure Care Permit Application (DOE, 1988) as saturated surficial materials including Rocky Flats alluvium, disturbed alluvium, colluvium, and North Walnut Creek valley fill alluvium. In addition, the uppermost aquifer includes outcropping weathered claystones and those sandstones and weathered claystones of the Arapahoe Formation which subcrop beneath the surficial materials within the waste management area. Any sandstone which does not meet this criteria but is hydraulically connected with sandstones that subcrop beneath the surficial materials within the waste management area are also considered part of the uppermost aquifer. Each subcropping or hydraulically connected sandstone is part of the uppermost aquifer to such depth where the sandstone

pinches stratigraphically. Subcropping weathered claystones are a part of the uppermost aquifer to the base of weathering.

Although the surficial materials as well as subcropping and interconnected bedrock units present beneath the solar evaporation ponds are defined as the uppermost aquifer for groundwater monitoring purposes, they do not meet the definition of an "aquifer" as defined in 40 CFR. Because of their insufficient saturated thickness and low conductivity, it is unlikely that these units will be developed for consumptive groundwater use.

An uppermost aquifer is defined in 40 CFR Part 260.10 as "the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary."

Aquifer is defined in 40 CFR Part 270.2 as "a geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring."

A "significant source of ground water" as used in 40 CFR Part 191 (Environmental radiation protection standards for management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes) means:

(1) an aquifer that:

(i) is saturated with water having less than 10,000 milligrams per liter of total dissolved solids;

(ii) is within 2,500 feet of the land surface;

(iii) has a transmissivity greater than 200 gallons per day per foot, provided that any formation or part of a formation included within the source of groundwater has a hydraulic conductivity greater than 2 gallons per day per square foot ( $5.3 \times 10^{-3}$  centimeters per second (cm/sec)); and

(iv) is capable of continuously yielding at least 10,000 gallons per day (6.9 gallons per minute) to a pumped or flowing well for a period of at least a year; or

- (2) an aquifer that provides the primary source of water for a community water system as part of the effective date of this subpart.

Surficial materials beneath the solar evaporation ponds do not qualify as an aquifer because they are not continuously saturated. Based on 1988 water level data, areas of unsaturated surficial materials are present to the south, east, northeast, and northwest of the ponds (DOE, 1988). Thus, these materials are incapable of yielding significant amounts of water to a well as defined in 40 CFR Part 191 and do not constitute an aquifer.

Bedrock materials beneath the solar evaporation ponds consist of silty sandstones, siltstones, and claystones with low hydraulic conductivities. Drawdown-recovery tests, slug tests, and packer tests have been conducted on bedrock materials at the solar evaporation ponds to evaluate hydraulic conductivities. Based on analyses of available test data, the average hydraulic conductivity of the bedrock units is as follows:

Silty Sandstones	-	$5 \times 10^{-7}$ cm/sec ( $1.9 \times 10^{-4}$ gallons per day per square foot (gal/day-ft <sup>2</sup> ))
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Siltstone -  $7 \times 10^{-7}$  cm/sec  
 ( $2.7 \times 10^{-4}$  gal/day-ft<sup>2</sup>)

Weathered Claystone -  $4 \times 10^{-7}$  cm/sec  
 ( $1.5 \times 10^{-4}$  gal/day-ft<sup>2</sup>)

A comparison of these results with the requirements for a "significant amount of water" indicates that these units do not meet the definition of an aquifer. Additional slug and pump tests are currently being performed at the solar evaporation ponds on newly installed wells in both surficial and bedrock materials, and this analysis will be reevaluated upon completion of the current investigations.

Due to the partially saturated conditions within surficial materials and the low hydraulic conductivities of bedrock materials in this area, it is unlikely that either of these units will ever be developed for groundwater use. Therefore, the groundwater pathway will not be considered in determining soil clean-up levels.

## SECTION 4.0

## TOXICITY ASSESSMENT

In a risk assessment, carcinogenic and noncarcinogenic risks are evaluated using human health toxicity values (i.e., reference doses and carcinogenic potency factors). Similarly, when determining target clean-up levels based on health risk, these toxicity values are factored into the algorithms that are used to compute acceptable soil concentrations. This section presents a discussion of the toxicity values that are used in the calculation of target clean-up levels in Section 5.0. The approach to developing the toxicity values was previously provided in a memo to Rockwell International. A copy of this memo is included in Appendix C.

In determining clean-up levels, both carcinogenic and noncarcinogenic health effects must be considered. Excessive exposure to all chemicals can potentially produce noncarcinogenic health effects, while the potential for carcinogenic effects is limited to exposure to certain substances. Therefore, it was necessary to identify and select noncarcinogenic risk-based toxicity values (reference doses) for each of the contaminants and to identify and select carcinogenic risk-based toxicity values (carcinogenic potency factors) for those chemicals having evidence of carcinogenicity.

Carcinogenic potency factors (CPFs) and reference doses (RfDs) are developed for specific exposure routes. Oral values were therefore used to evaluate the incidental soil ingestion and vegetable ingestion exposure routes and inhalation values were used to evaluate exposure through the inhalation of airborne contaminated soil and the inhalation of vapors. There were no toxicity values available for the dermal route and there were inadequate data from which to derive dermal values. Therefore, the most conservative available value for a chemical, inhalation or oral, was used to evaluate exposure through dermal con-

tact with soil. With the exceptions of mercury and cyanide, the dermal absorption of the inorganic contaminants from a soil matrix is expected to be negligible, and was not considered in determining target cleanup levels. Because sewage sludge was disposed in the solar ponds (DOE, 1987), it is possible that any mercury present in the ponds may have become biotransformed to an organic form. Because alkyl mercury compounds are lipid soluble, significant dermal absorption of mercury could potentially occur. Similarly, cyanides are moderately lipid-soluble, which allows them to penetrate the skin (ATSDR, 1988a).

#### 4.1 CARCINOGENIC POTENCY FACTORS

Eighteen of the site contaminants have been categorized as carcinogens (i.e., classified in Groups A, B, or C) by the U.S. EPA. Although lead is classified by the U.S. EPA as a carcinogen (Group B2), EPA recommends that its carcinogenicity not be quantitated for the purpose of risk assessment because of the uncertainty of its carcinogenic potency. However, EPA has stated that lead does not appear to be a potent carcinogen and that at low doses "the non-cancer effects of lead are of greatest concern for regulatory purposes" (EPA, 1988). Therefore, lead is not considered in determining clean-up levels based on carcinogenic risk. The 17 carcinogenic chemicals addressed in this evaluation and their U.S. EPA and IARC (International Agency for Research on Cancer) carcinogenicity classifications are presented in Table 4-1. An explanation of the U.S. EPA and IARC carcinogenicity classification systems is presented in Table 4-2.

Potency factors for benzo(a)pyrene were used to evaluate the carcinogenic PAHs. Benzo(a)pyrene is one of the most potent carcinogens of the PAHs that have been tested for carcinogenicity. The use of the potency factors for benzo(a)pyrene to represent all carcinogens is expected to provide a conservative estimate of health protective clean-up levels for PAHs.

Table 4-1

EPA and IARC Categorizations of the  
Carcinogenic Site Contaminants

Chemical	EPA Carcinogenicity Category <sup>1</sup>	IARC Carcinogenicity Category <sup>2</sup>
<u>Organics</u>		
Bis(2-ethylhexyl)phthalate	B2	2B
Carbon tetrachloride	B2	2B
Chloroform	B2	2B
1,1-Dichloroethane	B2 <sup>3</sup>	NL
1,2-Dichloroethane	B2	2B
1,2-Dichloroethene	C	NL
Methylene chloride	B2	3
PAHs (carcinogenic) (as benzo(a)pyrene)	B2 <sup>4</sup>	2A <sup>4</sup>
Tetrachloroethene	B2	2B
1,1,2-Trichloroethane	C	3
Trichloroethene	B2	3
Vinyl chloride	A	1
<u>Inorganics</u>		
Arsenic	A	1
Beryllium	B2	2A
Cadmium	B1 <sup>5</sup>	2A
Chromium (VI)	A <sup>5</sup>	1
Nickel	A <sup>5</sup>	1

<sup>1</sup>Reference: EPA, 1989a.

<sup>2</sup>Reference: WHO, 1987.

<sup>3</sup>Classification is for the oral route. 1,1-Dichloroethane is not currently categorized by EPA as to its carcinogenicity through the inhalation route.

<sup>4</sup>Classification is for benzo(a)pyrene. Carcinogenic PAHs are treated in this evaluation as benzo(a)pyrene (see text, Subsection 4.1).

<sup>5</sup>Classification is for the inhalation route. There are inadequate data for the toxicity of this chemical by the oral route (EPA, 1989a).

NL - Not listed.



Table 4-2

**EPA and IARC Categorizations of Carcinogens  
Based on Human and Animal Evidence**

EPA Categorization of Carcinogens <sup>1</sup>					
	Animal Evidence				
	Sufficient	Limited	Inadequate	No Data	No Evidence
<u>Human Evidence</u>					
Sufficient	A	A	A	A	A
Limited	B1	B1	B1	B1	B1
Inadequate	B2	C	D	D	D
No data	B2	C	D	D	E
No evidence	B2	C	D	D	E

Key:

- Group A - Human carcinogen (sufficient evidence from epidemiological studies).
- Group B1 - Probable human carcinogen (at least limited evidence of carcinogenicity to humans).
- Group B2 - Probable human carcinogen (a combination of sufficient evidence in animals and inadequate data in humans).
- Group C - Possible human carcinogen (limited evidence in animals in the absence of human data).
- Group D - Not classified (inadequate animal and human data).
- Group E - No evidence for carcinogenicity (no evidence for carcinogenicity in at least two adequate animal tests in different species, or in both epidemiological and animal studies).

IARC Categorization of Carcinogens<sup>2</sup>

- Group 1 - Human carcinogen (sufficient evidence of carcinogenicity in humans).
- Group 2A - Probable human carcinogen (limited evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in experimental animals).

**Table 4-2**  
(continued)

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IARC Categorization of Carcinogens<sup>2</sup>

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- Group 2B - Possible human carcinogen (limited evidence of carcinogenicity in humans and insufficient evidence of carcinogenicity in experimental animals; insufficient evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in experimental animals; or insufficient evidence of carcinogenicity in humans and limited evidence of carcinogenicity in experimental animals, with supporting evidence from other relevant data).
- Group 3 - Not classifiable (substances in this category do not fall into any other category).
- Group 4 - Probably not carcinogenic to humans.
- 

<sup>1</sup>EPA, 1986c

<sup>2</sup>WHO, 1987

Current oral and inhalation potency factors were available for most of the contaminants. In the absence of current oral and inhalation potency factors for benzo(a)pyrene, older previously developed factors were used. Neither current nor older inhalation potency factors were available for bis(2-ethylhexyl)phthalate and 1,1-dichloroethane. Because organic compounds are usually well absorbed through both the oral and inhalation routes, their systemic toxic effects through both routes are usually similar. Therefore, in the absence of inhalation potency factors for bis(2-ethylhexyl)phthalate and 1,1-dichloroethane, the current oral potency factors were used for the inhalation route.

The carcinogenic potency factors used in determining soil clean-up levels based on carcinogenic risk are presented in Table 4-3.

#### 4.2 REFERENCE DOSES

The toxicity values used to evaluate the potential for noncarcinogenic health effects are generically referred to in this document as reference doses (RfDs). The term reference dose was developed by EPA to refer to a daily intake of a chemical to which an individual can be exposed over a given length of time without any reasonable expectation of noncarcinogenic adverse health effects occurring. The term is used in this assessment to apply to any established or derived value fitting this description. Unlike the approach used in evaluating carcinogenic risk, it is assumed for noncarcinogenic health effects that a threshold dose exists below which there is no appreciable potential for toxicity.

Because the soil clean-up levels are intended to protect individuals for exposure periods of up to a lifetime, chronic RfDs were used to derive target soil concentrations. Current chronic oral reference doses were available for 25 of the 35 site contaminants (EPA, 1989a). An older oral RfD was used for tri-

Table 4-3

Carcinogenic Potency Factors  
(mg/kg/day)<sup>-1</sup>

Chemical	Oral <sup>1</sup>	Inhalation <sup>1</sup>	Dermal <sup>2</sup>
<u>Organics</u>			
Bis(2-ethylhexyl) phthalate	1.40E-02	1.40E-02 <sup>3</sup>	1.40E-02
Carbon tetrachloride	1.30E-01	1.30E-01	1.30E-01
Chloroform	6.10E-03	8.10E-02	8.10E-02
1,1-Dichloroethane	9.10E-02	9.10E-02 <sup>3</sup>	9.10E-02
1,2-Dichloroethane	9.10E-02	9.10E-02	9.10E-02
1,1-Dichloroethene	6.00E-01	1.20E+00	1.20E+00
Methylene chloride	7.50E-03	1.65E-03 <sup>4</sup>	7.50E-03
PAHs(carcinogenic) (as benzo(a)pyrene)	1.15E+01 <sup>5</sup>	6.10E+00 <sup>5</sup>	1.15E+01
Tetrachloroethene	5.10E-02	3.30E-03	5.10E-02
1,1,2-Trichloroethane	5.70E-02	5.70E-02	5.70E-02
Trichloroethene	1.10E-02	1.70E-02	1.70E-02
Vinyl chloride	2.30E+00	2.95E-01	2.30E+00
<u>Inorganics</u>			
Arsenic	1.75E+00 <sup>6</sup>	5.00E+01	NC
Beryllium	4.30E+00 <sup>7</sup>	8.40E+00	NC
Cadmium	NA	6.10E+00	NC
Chromium (VI)	NA	4.10E+01	NC
Nickel	NA	8.40E-01	NC

<sup>1</sup>Unless otherwise noted, the source of the potency factor is EPA, 1989a.

<sup>2</sup>The dermal potency factor represents the highest (i.e., most conservative) available potency factor, oral or inhalation.

<sup>3</sup>The oral potency factor was used.

<sup>4</sup>Converted from a unit risk factor of 4.7E-07 (ug/m<sup>3</sup>)<sup>-1</sup> by assuming the inhalation of 20 m<sup>3</sup>/day and a body weight of 70 kg (EPA, 1989d).

<sup>5</sup>A carcinogenic potency factor is not currently available from EPA for benzo(a)pyrene (EPA, 1989a). In the absence of a current value, a previously calculated potency factor was used (EPA, 1986c).

<sup>6</sup>Calculated from a potency factor of 5 x 10<sup>-5</sup> (ug/l)<sup>-1</sup> (EPA, 1989c) assuming the consumption of 2 liters of water/day and a body weight of 70 kg (EPA, 1989d).

<sup>7</sup>Reference: IRIS, 1990.

NA - Not applicable. There is inadequate evidence for the carcinogenicity of this chemical by the oral route (EPA, 1989a).

NC - Chemical is not of concern through this exposure route (see text, Section 4.0).

chloroethene. Oral RfDs were derived for the remaining nine chemicals (iron, lead, lithium, strontium, sulfate, uranium, 1,2-dichloroethane, PAHs, and vinyl chloride) based on available health-based standards or toxicological information. The approaches used to derive oral RfDs for these chemicals are described in Appendix D.

Current chronic inhalation RfDs were available for only six contaminants (EPA, 1989a): barium, 2-butanone, 1,1-dichloroethane, methylene chloride, toluene, and 1,1,1-trichloroethane. With the exception of lithium, inhalation RfDs were derived for the rest of the contaminants based on a threshold limit value-time weighted average (TLV-TWA) developed by the American Conference of Industrial Hygienists (ACGIH, 1989). A TLV-TWA is intended to protect healthy workers from adverse health effects when repeatedly exposed to a substance in the workplace air for 8 hours/day, 5 days/week. Because the TLV-TWA for some chemicals may be based on an endpoint other than chronic noncarcinogenic effects (e.g., acute irritation, carcinogenicity), the data on which each TLV-TWA was based were reviewed to ensure that the TLV-TWA was an appropriate value from which to derive an inhalation RfD (ACGIH, 1986). However, since TLV-TWAs are based on the most sensitive endpoint, the derived RfDs are expected to be protective of potential noncarcinogenic adverse health effects. The equation used to derive inhalation RfDs from TLV-TWAs is presented in Table 4-4.

The inhalation RfD for PAHs was based on the TLV-TWA for naphthalene, incorporating an uncertainty factor of 100 to take into consideration possible differences in noncarcinogenic effects between naphthalene and the PAHs which may be present on site.

TLV-TWAs were not available for nitrate, strontium, sulfate, or uranium, nor were there any data in the surveyed literature from which to derive inhalation RfDs. Therefore, the TLV-TWA for

Table 4-4

**Approach to Deriving an Inhalation Reference  
Dose (RfD) From a Threshold Limit Value-  
Time Weighted Average (TLV-TWA)**

Inhalation RfD (mg/kg/day)	=	$\frac{\text{TLV-TWA (mg/m}^3\text{)} \times \text{Air breathed per work day (m}^3\text{/day)}}{\text{Body weight (kg)} \times \text{Uncertainty factor}}$	Work week adjustment factor
where:			
Inhalation RfD	=	Inhalation reference dose.	
TLV-TWA	=	Threshold limit value-time weighted average (ACGIH, 1989).	
Air breathed per work day	=	10 m <sup>3</sup> . This value has been used by EPA when deriving an inhalation acceptable chronic intake (AIC) for the public from worker exposure levels (EPA, 1984a).	
Work week adjustment factor	=	5 days/7 days. Because the TLV-TWA is based on a 5-day work week, an adjustment was made to average the daily dose over a 7 day week.	
Body weight	=	70 kg (weight of an average adult) (EPA, 1989d).	
Uncertainty factor <sup>1</sup>	=	100. An uncertainty factor of 10 was applied to account for human variation (i.e., to protect sensitive members of the general population) (EPA, 1989d). An additional modifying factor of 10 was included to take into account a continuous exposure for a resident (versus an intermittent exposure for a worker) and a lifetime exposure for a resident (versus a less than lifetime exposure for a worker). Uncertainty factors of 10 to 100 have been used by government agencies when deriving public health criteria from TLV-TWAs (EPA, 1984a; MDNR, 1989; PAMS, 1983).	

<sup>1</sup>See Appendix D for a discussion of uncertainty factors.

"particulates not otherwise classified" was used as a default value from which to derive inhalation RfDs for these contaminants. Although a TLV-TWA was available for lithium hydride, it was not used to derive the inhalation RfD for lithium. The reason for not using this TLV-TWA and the approach used to derive the inhalation RfD for lithium are presented in Appendix D.

Oral and (derived) inhalation RfDs for hexavalent chromium (chromium VI) were used to determine soil clean-up levels for chromium. Chromium can exist in the environment in several valence states, trivalent being the most common. However, because hexavalent chromium was reportedly disposed of in the solar evaporation ponds (DOE, 1987), and because hexavalent chromium is more toxic than the trivalent form, the RfDs for hexavalent chromium were used.

The RfDs that were used in determining soil clean-up levels based on noncarcinogenic health risk are presented in Table 4-5.

Table 4-5  
Reference Doses (RfDs)  
(mg/kg/day)

Chemical	Oral	Reference or Basis	Inhalation	Reference or Basis	Dermal	Basis
<b>Organics</b>						
Acetone	1.0E-01	EPA, 1989a	1.8E+00	TLV-TWA	1.0E-01	ORFD
Bis(2-ethylhexyl) phthalate	2.0E-02	EPA, 1989a	5.1E-03	TLV-TWA	5.1E-03	IRFD
2-Butanone	5.0E-02	EPA, 1989a	9.0E-02	EPA, 1989a	5.0E-02	ORFD
Carbon tetrachloride	7.0E-04	EPA, 1989a	3.2E-02	TLV-TWA	7.0E-04	ORFD
Chloroform	1.0E-02	EPA, 1989a	5.0E-02	TLV-TWA	1.0E-02	ORFD
1,1-Dichloroethane	1.0E-01	EPA, 1989a	1.0E-01	EPA, 1989a	1.0E-01	IRFD, ORFD
1,2-Dichloroethane	7.4E-03	Derived	4.1E-02	TLV-TWA	7.4E-03	ORFD
1,1-Dichloroethene	9.0E-03	EPA, 1989a	2.0E-02	TLV-TWA	9.0E-03	ORFD
Ethylbenzene	1.0E-01	EPA, 1989a	4.4E-01	TLV-TWA	1.0E-01	ORFD
Methylene chloride	6.0E-02	EPA, 1989a	8.6E-01	EPA, 1989a <sup>1</sup>	6.0E-02	ORFD
PAHs	4.0E-05	Derived	5.1E-04	TLV-TWA <sup>2</sup>	5.1E-04	IRFD
Tetrachloroethene	1.0E-02	EPA, 1989a	3.5E-01	TLV-TWA	1.0E-02	ORFD
Toluene	3.0E-01	EPA, 1989a	5.7E-01	EPA, 1989a <sup>1</sup>	3.0E-01	ORFD
1,1,1-Trichloroethane	9.0E-02	EPA, 1989a	3.0E-01	EPA, 1989a	9.0E-02	ORFD
1,1,2-Trichloroethane	4.0E-03	EPA, 1989a	5.6E-02	TLV-TWA	4.0E-03	ORFD
Trichloroethene	7.4E-03	EPA, 1987a	2.7E-01	TLV-TWA	7.4E-03	ORFD
Vinyl chloride	1.3E-03	Derived	1.0E-02	TLV-TWA	1.3E-03	ORFD
<b>Inorganics<sup>3</sup></b>						
Arsenic	1.0E-03	EPA, 1989a	2.0E-04	TLV-TWA	NC	---
Barium	5.0E-02	EPA, 1989a	1.0E-04	EPA, 1989a	NC	---
Beryllium	5.0E-03	EPA, 1989a	2.0E-06	TLV-TWA	NC	---
Cadmium	1.0E-03 <sup>4</sup>	EPA, 1989a	5.1E-05	TLV-TWA	NC	---
Chromium (as VI)	5.0E-03	EPA, 1989a	5.1E-05	TLV-TWA	NC	---
Cyanide	2.0E-02	EPA, 1989a	5.1E-03	TLV-TWA	5.1E-03	IRFD
Iron	3.0E+00	Derived	1.0E-03	TLV-TWA	NC	---
Lead	1.4E-04	Derived	1.5E-04	TLV-TWA	NC	---
Lithium	2.4E-02	Derived	1.0E-04	Derived	NC	---
Mercury	3.0E-04	EPA, 1989a	1.0E-05	TLV-TWA <sup>5</sup>	NC	---
Nickel	2.0E-02	EPA, 1989a	1.0E-04	TLV-TWA <sup>6</sup>	1.0E-05	IRFD
Nitrate-Nitrite	1.0E-01	EPA, 1989a <sup>7</sup>	1.0E-02	TLV-TWA <sup>8</sup>	NC	---
Selenium	3.0E-03	EPA, 1989a	2.0E-04	TLV-TWA	NC	---



**Table 4-5**  
(continued)

Contaminant	Oral	Reference or Basis	Inhalation	Reference or Basis	Dermal	Basis
<u>Inorganics</u>						
Strontium	1.6E-03	Derived	1.0E-02	TLV-TWA <sup>8</sup>	NC	---
Sulfate	7.1E+00	Derived	1.0E-02	TLV-TWA <sup>8</sup>	NC	---
Thallium	7.0E-05	EPA, 1989a	1.0E-04	TLV-TWA		
Uranium	6.0E-04	Derived	1.0E-02	TLV-TWA <sup>8</sup>	NC	---
Vanadium	7.0E-03	EPA, 1989a	5.1E-05	TLV-TWA	NC	---

Derived = Value is derived from available toxicity information or an available health criterion. See Appendix D for the approach used in the derivation.

IRFD = Inhalation reference dose.

NC = Chemical is not of concern through this exposure route (see text).

ORFD = Oral reference dose.

TLV-TWA = Based on the Threshold Limit Value - Time-Weighted Average (ACGIH, 1989). See Table 4-4 for the approach to the derivation.

<sup>1</sup>Value was converted from mg/m<sup>3</sup> by assuming the inhalation of 20 m<sup>3</sup>/day and a 70 kg body weight (EPA, 1989d).

<sup>2</sup>Based on TLV-TWA for naphthalene, incorporating a modifying factor of 100 (See text, Subsection 4.2).

<sup>3</sup>The reference doses for the inorganics, unless otherwise indicated, are for "total" inorganic (i.e., they take into account all valence states and chemical species).

<sup>4</sup>Value is for food. Oral RFDs were available for cadmium for food and water. Because the oral exposure routes considered in this evaluation apply to food (i.e., vegetable ingestion) or other solid media (i.e., incidental soil ingestion), the value for food was used.

<sup>5</sup>Based on TLV-TWA for alkyl mercury. Because sanitary sewage sludge was disposed of in the ponds, it is possible that any inorganic mercury present may have become biotransformed to an organic form.

<sup>6</sup>Based on TLV-TWA for soluble nickel compounds.

<sup>7</sup>Value is for nitrite.

<sup>8</sup>Based on TLV-TWA for "particulates not otherwise classified" (see text, Subsection 4.2).

**SECTION 5.0****CALCULATION OF TARGET CLEAN-UP LEVELS FOR SOIL**

In this section, clean-up levels are derived for the soils beneath and surrounding the solar evaporation ponds. In determining clean-up levels based on carcinogenic and noncarcinogenic risks, it is assumed that the risks posed by individual contaminants are additive. This approach is in accord with current EPA guidance for assessing the total risk posed by the simultaneous presence of multiple substances (EPA, 1989d). According to EPA, if chemicals were assessed separately, it could significantly underestimate total risk in cases where additive interactions between chemicals might potentially occur. It is recognized by the Agency that this approach might also underestimate risk in cases where synergistic interactions might occur or overestimate risk in cases where antagonistic interactions are possible or where chemicals act independently. However, in the absence of information regarding the interactions of contaminants in a specific mixture found at a particular site, it is recommended by U.S. EPA that the additive approach be used (EPA, 1986a, 1989d). Because there is no information regarding the interactions of chemicals in mixtures similar to those found in solar pond soils, the additive approach was followed in determining risk-based clean-up levels.

Because sampling data were not available for the soils directly beneath the ponds, clean-up levels for these soils were calculated based on the assumption that all of the site contaminants may simultaneously be present beneath the ponds. Consequently, the clean-up levels derived for these soils represent the lowest calculated clean-up concentrations, since they take into account the potential additive toxicity of all 35 site contam-

inants. Clean-up levels based on the carcinogenic and noncarcinogenic risk posed by all of the site contaminants are derived in Subsections 5.1 and 5.2, respectively. Final clean-up levels based on the presence of all site contaminants are presented in Subsection 5.3.

Although it is possible that all of the site contaminants may be present beneath the solar ponds, based on the available soil sampling data (see Volume 2), it does not appear that all of the organic site contaminants are present throughout the soils surrounding the solar ponds. Similarly, all of the inorganic site contaminants do not appear to be present above background at all soil sampling locations. Therefore, different clean-up levels may have to be derived for different sections of the site. The approach to deriving location-specific clean-up levels is presented in Subsection 5.4.

## **5.1 DETERMINATION OF CLEAN-UP LEVELS BASED ON THE CARCINOGENIC RISK POSED BY ALL SITE CONTAMINANTS**

### **5.1.1 General Approach**

This subsection presents the general approach of the model used in calculating target clean-up levels based on potential carcinogenic risk. Details of the methodology are presented in Subsections 5.1.2 and 5.1.3. The model was based on a pre-selected risk criterion established during the July 14, 1989 preliminary meeting between Rockwell International and WESTON at the Rocky Flats Plant. At that time a total cancer risk of  $10^{-6}$  (one in one million) for all contaminants combined was chosen as the clean-up goal for carcinogenic contaminants.

Soil concentrations were first calculated for each carcinogen, allowing each chemical a total risk of  $10^{-7}$  (one in ten million) through all exposure routes. The soil concentration that would pose a  $10^{-7}$  risk through each key exposure route was de-

terminated for each contaminant. The  $10^{-7}$  risk soil concentration for each exposure route was then used to calculate a  $10^{-7}$  risk soil concentration for each contaminant through all exposure routes combined.

As previously discussed, it is assumed in determining clean-up levels that the carcinogenic risk posed by individual contaminants is additive. Because there are 17 carcinogenic contaminants being evaluated (see Table 4-1), assigning a maximum target risk level of  $10^{-7}$  to each carcinogenic chemical results in a total carcinogenic risk of approximately  $1.7 \times 10^{-6}$ . To achieve a clean-up goal of a  $10^{-6}$  cancer risk, the  $10^{-7}$  risk soil concentration for each contaminant was divided by 1.7.

#### 5.1.2 Determination of $10^{-7}$ Risk Soil Concentrations for Individual Exposure Routes

This subsection presents the mathematical models that were used to determine the  $10^{-7}$  risk soil concentrations for each contaminant through individual exposure routes. The models are presented in tabulated form. Each table includes the definition of the variables for the exposure route and the assumptions used in the model. Additional information regarding the assumptions is presented in the text. The approach used to derive the models is presented in Appendix E, Section E.1.

To simplify the calculations used in determining clean-up levels based on lifetime carcinogenic risk, exposure factors that are appropriate for calculating estimated daily intakes of contaminants by adults were used. Carcinogenic risk is expressed as risk posed over a lifetime of exposure. In calculating carcinogenic risk, risk due to childhood exposure is considered to be additive to the risk due to adult exposure, with both childhood and adult risk being proportional to estimated daily

intakes and exposure of duration. Although the estimated daily intakes of a child are usually greater than those of an adult on a body weight basis (see Subsection 5.2.2), because of the relatively short duration of childhood exposure, the increased daily intakes during childhood usually have only a small effect on overall lifetime carcinogenic risk. Because the major contribution to lifetime risk results from adult exposure, the exposure factors for the adult were used in preference to those for the child in simplifying the calculation of cancer risk-based clean-up levels.

#### 5.1.2.1 Incidental Soil Ingestion

The ingestion of contaminants present in soil can potentially occur indirectly through the placing of dirt-covered hands or objects (e.g., cigarettes) in the mouth. The model and assumptions that were used to calculate the soil concentration of contaminants that pose a  $10^{-7}$  cancer risk through incidental soil ingestion are presented in Table 5-1.

Residents are most likely to come into contact with soil during the months in which climatic conditions are conducive to outdoor yard activities. In Colorado, the exposure period is assumed to be approximately ten months (i.e., 40 weeks/year). The contaminant concentrations in soil which pose a  $10^{-7}$  risk through incidental soil ingestion are presented in Table 5-2.

#### 5.1.2.2 Vegetable Ingestion

It is possible that residents could be indirectly exposed to soil contaminants through the ingestion of vegetables grown in contaminated soil in a home garden. Although a variety of vegetables may potentially be raised by a resident, in this assessment root vegetables (e.g., carrots) were chosen to calculate target soil concentrations. Because root vegetables are

Table 5-1

Model for Determining the Soil Concentration  
of a Contaminant Posing a  $10^{-7}$  Cancer  
Risk Through Incidental Soil Ingestion

$$C_{\text{soil}} = \frac{\text{RISK} \times \text{BW}}{\text{SIR} \times \text{OPF} \times \text{W/Y} \times \text{CF}}$$

Variables:

$C_{\text{soil}}$	=	Contaminant concentration in the soil (mg/kg).
RISK	=	Carcinogenic risk over a 70 year lifetime (unitless).
BW	=	Body weight (kg).
SIR	=	Soil ingestion rate (mg/day).
OPF	=	Oral carcinogenic potency factor (mg/kg/day) <sup>-1</sup> .
W/Y	=	Number of weeks exposed per year (weeks/year).
CF	=	Conversion factors ( $10^{-6}$ kg/mg; 1 year/52 weeks).

Assumptions:

- (1) The carcinogenic risk (RISK) is  $10^{-7}$  (one in ten million).
- (2) The body weight (BW) of an average adult is 70 kg (EPA, 1989d).
- (3) The soil ingestion rate (SIR) of an adult is 100 mg/day (EPA, 1989b).
- (4) The oral carcinogenic potency factor (OPF) for each contaminant is presented in Table 4-3.
- (5) An individual is exposed 40 weeks per year (W/Y).

Table 5-2

Soil Concentrations Posing a  $10^{-7}$  Cancer  
Risk Through Incidental Soil Ingestion

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Bis(2-ethylhexyl)phthalate	6.50E+00
Carbon tetrachloride	7.00E-01
Chloroform	1.49E+01
1,1-Dichloroethane	1.00E+00
1,2-Dichloroethane	1.00E+00
1,1-Dichloroethene	1.52E-01
Methylene chloride	1.21E+01
PAHs (carcinogenic) (as benzo(a)pyrene)	7.91E-03
Tetrachloroethene	1.78E+00
1,1,2-Trichloroethane	1.60E+00
Trichloroethene	8.27E+00
Vinyl chloride	3.96E-02
<u>Inorganics</u>	
Arsenic	5.20E-02
Beryllium	2.12E-02

grown directly in the soil, they are likely to have the greatest potential for the accumulation of soil contaminants.

The model and assumptions that were used to calculate the concentrations of contaminants that pose a  $10^{-7}$  cancer risk through vegetable ingestion are presented in Table 5-3. The approaches used to calculate root uptake factors for root vegetables are presented in Appendix F. All input factors used in the computations were expressed in or adjusted for wet weight. A wet weight root vegetable ingestion rate was calculated based on an average dry weight root vegetable ingestion rate for adults aged 25-65 years (EPA, 1986b), adjusted for a moisture content of 88.2 percent (based on carrots) (Baes et al., 1984).

It was assumed that 50 percent of all root vegetables consumed during the year are homegrown. It has been reported that approximately 60 percent of the vegetables consumed by rural farm households are raised in home gardens (EPA, 1986a). It is expected that the typical suburban household grows a substantially smaller percentage of their vegetables than a rural farm household. However, a conservative value of 50 percent was used in this assessment to compensate for any additional exposure to contaminants that a resident might receive as a result of the ingestion of other types of homegrown produce (e.g., leafy vegetables, garden fruits).

The contaminant concentrations in soil which pose a  $10^{-7}$  risk through vegetable ingestion are presented in Table 5-4.

#### 5.1.2.3 Dermal Contact With Soil

In addition to posing the potential for the indirect ingestion of contaminants, contact with soil may also pose the potential for the absorption of contaminants through the skin. The model and assumptions that were used to calculate the concentrations



Table 5-3

Model for Determining the Soil Concentration  
of a Contaminant Posing a  $10^{-7}$  Cancer  
Risk Through Vegetable Ingestion

$$C_{\text{soil}} = \frac{\text{RISK} \times \text{BW}}{\text{VIR} \times \text{FR} \times \text{RUF} \times \text{OPF} \times \text{CF}}$$

Variables:

$C_{\text{soil}}$	=	Contaminant concentration in the soil (mg/kg).
RISK	=	Carcinogenic risk over a 70 year lifetime (unitless).
BW	=	Body weight (kg).
VIR	=	Root vegetable ingestion rate (g/day).
FR	=	Fraction of vegetables that are homegrown (unitless).
RUF	=	Root uptake factor (unitless).
OPF	=	Oral carcinogenic potency factor (mg/kg/day) $^{-1}$ .
CF	=	Conversion factor ( $10^{-3}$ kg/g).

Assumptions:

- (1) The carcinogenic risk (RISK) is  $10^{-7}$  (one in ten million).
- (2) The body weight (BW) of an average adult is 70 kg (EPA, 1989d).
- (3) The root vegetable ingestion rate (VIR) for an adult is 14.9 g/day (see text, Subsection 5.1.2.2).
- (4) The fraction of vegetables that is homegrown (FR) is 0.50 (see text, Subsection 5.1.2.2).
- (5) The root uptake factor (RUF) for each contaminant is presented in Appendix Table F-2.
- (6) The oral carcinogenic potency factor (OPF) for each contaminant is presented in Table 4-3.

Table 5-4

Soil Concentrations Posing a  $10^{-7}$  Cancer Risk  
Through Vegetable Ingestion

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Bis(2-ethylhexyl)phthalate	3.56E-01
Carbon tetrachloride	4.88E-03
Chloroform	6.58E-02
1,1-Dichloroethane	5.02E-03
1,2-Dichloroethane	2.92E-03
1,1-Dichloroethene	1.58E-03
Methylene chloride	2.45E-02
PAHs (carcinogenic) (as benzo(a)pyrene)	8.02E-03
Tetrachloroethene	4.35E-02
1,1,2-Trichloroethane	7.15E-03
Trichloroethene	9.36E-02
Vinyl chloride	4.98E-04
<u>Inorganics</u>	
Arsenic	7.58E-01
Beryllium	1.23E+00

of contaminants that pose a  $10^{-7}$  cancer risk through dermal contact with soil are presented in Table 5-5.

There are few data regarding the absorption of chemicals from a soil matrix. Studies have indicated that approximately one to two percent of soil-bound dioxins are absorbed through the skin (Poiger and Schlatter, 1980; Shu et al., 1988). In the absence of specific skin absorption data for the site contaminants, an absorption factor of two percent (0.02) was used for all of the organic chemicals, as well as for mercury and cyanide.

The amount of soil adhering to skin has been reported to range from approximately 0.5 to 2.77 mg soil/cm<sup>2</sup> skin (Schaum, 1984; EPA, 1989d). A value of 1.45 mg/cm<sup>2</sup> which has been estimated for commercial potting soil, and which is close to the midpoint of the range, was used in this evaluation. Only the hands and arms were assumed to be exposed to soil during outdoor activities; the average of the upper extremities' surface area for adult males and females was used (Anderson et al., 1985). The duration of exposure was assumed to be the same as that for incidental soil ingestion (i.e., 40 weeks/year).

The contaminant concentrations in soil which pose a  $10^{-7}$  risk through dermal contact with soil are presented in Table 5-6.

#### 5.1.2.4 Inhalation of Airborne Contaminated Soil

Residents can potentially be exposed to contaminants through the inhalation of dusts generated from contaminated soil. The model and assumptions that were used to determine the contaminant concentrations in soil that pose a  $10^{-7}$  cancer risk through the inhalation of airborne contaminated soil are presented in Table 5-7.

It was assumed that an individual could potentially be exposed to airborne contaminated soil on a 24-hour basis. Although an

Table 5-5

**Model for Determining the Soil Concentration  
of a Contaminant Posing a  $10^{-7}$  Cancer  
Risk Through Dermal Contact With Soil**

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$$C_{\text{soil}} = \frac{\text{RISK} \times \text{BW}}{\text{ESA} \times \text{SA} \times \text{AF} \times \text{DPF} \times \text{W/Y} \times \text{CF}}$$

**Variables:**

$C_{\text{soil}}$	= Contaminant concentration in the soil (mg/kg).
RISK	= Carcinogenic risk over a 70 year lifetime (unitless).
BW	= Body weight (kg).
ESA	= Exposed skin surface area ( $\text{cm}^2/\text{day}$ ).
SA	= Skin adherence factor ( $\text{mg}/\text{cm}^2$ ).
AF	= Dermal absorption factor (unitless).
DPF	= Dermal potency factor ( $\text{mg}/\text{kg}/\text{day}$ ) <sup>-1</sup> .
W/Y	= Number of weeks exposed per year (weeks/year).
CF	= Conversion factors ( $10^{-6}$ kg/mg; 1 year/52 weeks).

---

**Assumptions:**

- (1) The carcinogenic risk (RISK) is  $10^{-7}$  (one in ten million).
- (2) The body weight (BW) of an average adult is 70 kg (EPA, 1989d).
- (3) The exposed skin surface area (ESA) is  $2,980 \text{ cm}^2/\text{day}$  (see text, Subsection 5.1.2.3).
- (4) The skin adherence factor (SA) is  $1.45 \text{ mg}/\text{cm}^2$  (see text, Subsection 5.1.2.3).
- (5) The dermal absorption factor (AF) is 0.02 (see text, Subsection 5.1.2.3).
- (6) The dermal carcinogenic potency factor (DPF) for each contaminant is presented in Table 4-3.
- (7) An individual is exposed 40 weeks per year (W/Y).

Table 5-6

Soil Concentrations Posing a  $10^{-7}$  Cancer Risk  
Through Dermal Contact With Soil

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Bis(2-ethylhexyl)phthalate	7.53E+00
Carbon tetrachloride	8.11E-01
Chloroform	1.30E+00
1,1-Dichloroethane	1.16E+00
1,2-Dichloroethane	1.16E+00
1,1-Dichloroethene	8.79E-02
Methylene chloride	1.41E+01
PAHs (carcinogenic) (as benzo(a)pyrene)	9.17E-03
Tetrachloroethene	2.07E+00
1,1,2-Trichloroethane	1.85E+00
Trichloroethene	6.20E+00
Vinyl chloride	4.59E-02

Table 5-7

**Model for Determining the Soil Concentration of a  
Contaminant Posing a  $10^{-7}$  Cancer Risk Through  
the Inhalation of Airborne Contaminated Soil**

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$$C_{\text{soil}} = \frac{\text{RISK} \times \text{CRF}}{\text{IURF} \times F_1 \times \text{PM}_{10}\text{EF} \times \text{ASP} \times \text{CF}}$$

**Variables:**

$C_{\text{soil}}$  = Contaminant concentration in the soil (mg/kg).  
 $\text{RISK}$  = Carcinogenic risk over a 70 year lifetime (unitless).  
 $\text{CRF}$  = Climatic region factor (unitless)  
 $\text{IURF}$  = Inhalation unit risk factor ( $\text{ug}/\text{m}^3$ )<sup>-1</sup>  
 $F_1$  = Unscaled concentration due to a unit erosion rate  
           ( $\text{ug}/\text{m}^3$ )/(g/sec)  
 $\text{PM}_{10}\text{EF}$  =  $\text{PM}_{10}$  (respirable size particles) emission factor  
           ( $\text{mg}/\text{m}^2/\text{hr}$ )  
 $\text{ASP}$  = Area of the solar ponds ( $\text{m}^2$ )  
 $\text{CF}$  = Conversion factors ( $10^{-3}$  g/mg;  $10^{-6}$  kg/mg; 1hr/  
           3,600 sec).

---

**Assumptions:**

- (1) The carcinogenic risk ( $\text{RISK}$ ) is  $10^{-7}$  (one in ten million).
- (2) The climatic region factor is 0.262 for climatic region 2 and 0.396 for climatic region 3 (EPA, 1985b).
- (3) The inhalation unit risk factor ( $\text{IURF}$ ) for each contaminant is presented in Table 5-8.
- (4)  $F_1$  is 2.978 and 4.789 for climatic regions 2 and 3, respectively.
- (5) The  $\text{PM}_{10}$  emission factor ( $\text{PM}_{10}\text{EF}$ ) is 4,097  $\text{mg}/\text{m}^2/\text{hr}$ . (The  $\text{PM}_{10}\text{EF}$  is derived in Appendix G.
- (6) The area of the solar ponds ( $\text{ASP}$ ) is 25,086  $\text{m}^2$  (estimated).

Table 5-8

Inhalation Unit Risk Factors for the  
Carcinogenic Site Contaminants<sup>1</sup>

Chemical	Unit Risk (ug/m <sup>3</sup> ) <sup>-1</sup>
<u>Organics</u>	
Bis(2-ethylhexyl)phthalate	4.0E-06 <sup>2</sup>
Carbon tetrachloride	1.5E-05
Chloroform	2.3E-05
1,1-Dichloroethane	2.6E-05 <sup>2</sup>
1,2-Dichloroethane	2.6E-05
1,1-Dichloroethene	5.0E-05
Methylene chloride	4.7E-07
PAHs (carcinogenic) (as benzo(a)pyrene)	1.7E-03 <sup>3</sup>
Tetrachloroethene	9.5E-07
1,1,2-Trichloroethane	1.6E-05
Trichloroethene	1.7E-06
Vinyl chloride	4.2E-05
<u>Inorganics</u>	
Arsenic	4.3E-03
Beryllium	2.4E-03
Cadmium	1.8E-03
Chromium (as VI)	1.2E-02
Nickel	2.4E-04 <sup>4</sup>

<sup>1</sup>Risk posed by an air concentration of 1 ug/m<sup>3</sup>, assuming continuous lifetime exposure. Reference: EPA, 1989a except where noted otherwise.

<sup>2</sup>Neither an inhalation potency factor nor an inhalation unit risk factor was available. The unit risk was calculated based on the oral potency factor (EPA, 1989a), assuming the inhalation of 20 m<sup>3</sup>/day and a body weight of 70 kg (EPA, 1989d).

<sup>3</sup>EPA does not currently list an inhalation unit risk factor or any potency factors for benzo(a)pyrene (EPA, 1989a). The unit risk factor was derived from a previously listed inhalation potency factor (EPA, 1986c), by assuming the inhalation of 20 m<sup>3</sup>/day and a body weight of 70 kg (EPA, 1989d).

<sup>4</sup>Value is for nickel refinery dust.

individual would not be outdoors all day, airborne soil can enter a residence through open windows and doors. In addition, contaminated soil can be tracked into the house and then become resuspended. Because the Rocky Flats Plant is located on the border of climatic regions 2 and 3 as defined by U.S. EPA (EPA, 1985b), two sets of  $10^{-7}$  risk soil concentrations were calculated using climatic region factors and  $F_1$  factors that are specific to these regions, respectively.  $F_1$  which is defined as an unscaled concentration due to a unit erosion rate (i.e., a normalized ambient concentration for a unit emission rate) was the maximum value from a 100 M x 100 M fine grid (EPA, 1985b).

The contaminant concentrations in soil which pose a  $10^{-7}$  cancer risk through the inhalation of airborne contaminated soils are presented in Table 5-9. The most conservative soil concentrations (i.e., those calculated using climatic region 3 factors) were used in Section 5.1.3 to determine the soil concentrations based on all exposure routes combined.

#### **5.1.2.5 Inhalation of Vapors**

In addition to being exposed to airborne contaminants through the inhalation of dusts, residents may also be exposed to airborne contaminants through the inhalation of vapors resulting from the volatilization of contaminants from surface soils. Only the organic site contaminants are considered through the inhalation of vapors exposure route, because these are the site contaminants that may undergo substantial volatilization.

The model and assumptions that were used to determine the contaminant concentrations in soil that pose a  $10^{-7}$  cancer risk through the inhalation of vapors are presented in Table 5-10. The approach to deriving  $F_a$ , the fraction of the contaminant released to the air during 70 years, is described in Appendix H.



Table 5-9

Soil Concentrations Posing a  $10^{-7}$  Cancer Risk  
Through the Inhalation of Airborne Contaminated Soil

Chemical	Soil Concentration <sup>1</sup> (mg/kg)	
	Region 2	Region 3
<u>Organics</u>		
Bis(2-ethylhexyl)phthalate	7.70E+01	7.24E+01
Carbon tetrachloride	2.06E+01	1.94E+01
Chloroform	1.33E+01	1.25E+01
1,1-Dichloroethane	1.17E+01	1.10E+01
1,2-Dichloroethane	1.17E+01	1.10E+01
1,1-Dichloroethene	6.13E+00	5.79E+00
Methylene chloride	6.47E+02	6.08E+02
PAHs (carcinogenic) (as benzo(a)pyrene)	1.76E-01	1.65E-01
Tetrachloroethene	3.39E+02	3.19E+02
1,1,2-Trichloroethane	1.94E+01	1.82E+01
Trichloroethene	1.82E+02	1.71E+02
Vinyl chloride	7.40E+00	6.95E+00
<u>Inorganics</u>		
Arsenic	7.09E-02	6.66E-02
Beryllium	1.29E-01	1.22E-01
Cadmium	1.73E-01	1.62E-01
Chromium (as VI)	2.56E-02	2.40E-02
Nickel	1.29E+00	1.22E+00

<sup>1</sup>Calculated using climatic region factors and  $F_1$  factors  
for regions 2 and 3 (see text, Subsection 5.1.2.4).

Table 5-10

**Model for Determining the Soil Concentration  
of a Contaminant Posing a  $10^{-7}$  Cancer Risk  
Through the Inhalation of Vapors**

$$C_{\text{soil}} = \frac{\text{RISK} \times T}{\text{IURF} \times P_{\text{soil}} \times \text{ASP} \times F_a \times L \times X/Q \times \text{CF}}$$

**Variables:**

$C_{\text{soil}}$	= Contaminant concentration in the soil (mg/kg).
RISK	= Carcinogenic risk over a 70 year lifetime (unitless).
T	= Time after the waste is applied to the soil (sec).
IURF	= Inhalation unit risk factor $(\text{ug}/\text{m}^3)^{-1}$ .
$P_{\text{soil}}$	= Density of the soil $(\text{g}/\text{cm}^3)$ .
ASP	= Area of the solar ponds $(\text{m}^2)$ .
$F_a$	= Fraction of the contaminant released to the air during 70 years (unitless).
L	= Depth of contaminated soil (cm).
X/Q	= Contaminant concentration in air/emissions rate $(\text{ug}/\text{m}^3)/(\text{g}/\text{sec})$ .
CF	= Conversion factors $(10^{-4} \text{ cm}^2/\text{m}^2; 10^{-6} (\text{g}/\text{g})/(\text{mg}/\text{kg}))$ .

**Assumptions:**

- (1) The carcinogenic risk (RISK) is  $10^{-7}$  (one in ten million).
- (2) The time after the waste is applied to the soil (T) is equal to a 70 year lifetime,  $2.21 \times 10^9$  sec.
- (3) The inhalation unit risk factor (IURF) for each contaminant is presented in Table 5-9.
- (4) The density of the soil ( $P_{\text{soil}}$ ) is the density reported for packed dry earth,  $1.5 \text{ g}/\text{cm}^3$  (Baumeister et al., 1978).
- (5) The area of the solar ponds (ASP) is  $25,086 \text{ m}^2$  (estimated).
- (6) The fraction of the compound released to the air during 70 years ( $F_a$ ) is presented in Appendix Table H-1.
- (7) The depth of contaminated soil (L) is 121 cm (estimated).
- (8) The contaminant concentration in air/emissions rate (X/Q) is approximately  $2.978 (\text{ug}/\text{m}^3)/(\text{g}/\text{s})$  for climatic region 2 and  $4,789 (\text{ug}/\text{m}^3)/(\text{g}/\text{s})$  for climatic region 3 (EPA, 1985b).

As in the case of the inhalation of contaminated airborne soil exposure route, two sets of  $10^{-7}$  risk soil concentrations were calculated. The two sets were based on X/Q factors for climatic regions 2 and 3, respectively. The most conservative soil concentrations (i.e., those based on the climatic region 3 factor) were used in Section 5.1.3 to determine the soil concentrations based on all exposure routes combined. Also, as in the case of contaminated airborne soil, it is assumed that an individual could potentially be exposed to volatilized contaminants for 24 hours per day.

The contaminant concentrations in soil which pose a  $10^{-7}$  cancer risk through the inhalation of vapors are presented in Table 5-11.

### 5.1.3 Determination of Soil Concentrations Posing a $10^{-7}$ Cancer Risk Through All Exposure Routes Combined

For each carcinogenic site contaminant, the soil concentration that poses a  $10^{-7}$  lifetime cancer risk through all exposure routes combined was determined based on the  $10^{-7}$  risk soil concentrations calculated in Section 5.1.2 for the individual exposure routes. The following equation was used to calculate multiroute  $10^{-7}$  risk soil concentration for each chemical (Rosenblatt et al., 1982).

$$CCS-C = 1/(1/C_{SI} + 1/C_{VI} + 1/C_{DC} + 1/C_{IS} + 1/C_{IV})$$

where,

CCS-C = The contaminant concentration in soil posing a  $10^{-7}$  cancer risk through all exposure routes combined (mg/kg).

$C_{SI}$  = The contaminant concentration in soil posing a  $10^{-7}$  cancer risk through incidental soil ingestion (mg/kg).

Table 5-11

Soil Concentrations Posing a  $10^{-7}$  Cancer Risk  
Through the Inhalation of Vapors

Chemical	Soil Concentration <sup>1</sup> (mg/kg)	
	Region 2	Region 3
<u>Organics</u>		
Bis(2-ethylhexyl)phthalate	2.46E+06	1.53E+06
Carbon tetrachloride	1.09E+02	6.76E+01
Chloroform	6.95E+01	4.32E+01
1,1-Dichloroethane	6.13E+01	3.81E+01
1,2-Dichloroethane	6.16E+01	3.83E+01
1,1-Dichloroethene	3.22E+01	2.00E+01
Methylene chloride	3.38E+03	2.10E+03
PAHs (carcinogenic) (as benzo(a)pyrene)	9.52E+01	5.92E+01
Tetrachloroethene	1.81E+03	1.13E+03
1,1,2-Trichloroethane	1.06E+02	6.58E+01
Trichloroethene	9.62E+02	5.98E+02
Vinyl chloride	3.86E+01	2.40E+01

<sup>1</sup>Calculated using X/Q estimated for climatic regions 2 and 3  
(see text, Subsection 5.1.2.5).

$C_{VI}$  = The contaminant concentration in soil posing a  $10^{-7}$  cancer risk through vegetable ingestion (mg/kg).

$C_{DC}$  = The contaminant concentration in soil posing a  $10^{-7}$  cancer risk through dermal contact with soil (mg/kg).

$C_{IS}$  = The contaminant concentration in soil posing a  $10^{-7}$  cancer risk through the inhalation of airborne contaminated soil (mg/kg).

$C_{IV}$  = The contaminant concentration in soil posing a  $10^{-7}$  cancer risk through the inhalation of vapors (mg/kg).

The algebraic expression, as described by Rosenblatt et al., accounts for the fact that to protect human health, the receptors should not receive a combined daily dose from all exposure pathways in excess of the dose on which the target risk level is based. The equation adjusts the soil concentrations such that the individual pathways of exposure (e.g., incidental soil ingestion, dermal contact, etc.) taken together provide the receptor with the target dose value. As Rosenblatt et al. explains, "this calculation is similar to the addition of electrical resistances in parallel DC circuits." In computing the total resistance ( $R_{total}$ ) for several resistances connected in parallel, the inverse of the total resistance ( $1/R_{total}$ ) is equal to the sum of the inverses of the individual resistances ( $1/R_N$ ) in the circuit:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_N}$$

The soil concentration of each contaminant which poses a  $10^{-7}$  cancer risk through all exposure routes combined is presented in Table 5-12. The  $10^{-7}$  risk soil concentrations for indivi-

Table 5-12

Soil Concentrations Resulting in a  $1.7 \times 10^{-6}$   
Total Cancer Risk from All Contaminants  
Through All Exposure Routes Combined<sup>1</sup>

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Bis(2-ethylhexyl)phthalate	3.22E-01
Carbon tetrachloride	4.81E-03
Chloroform	6.20E-02
1,1-Dichloroethane	4.97E-03
1,2-Dichloroethane	2.91E-03
1,1-Dichloroethene	1.54E-03
Methylene chloride	2.45E-02
PAHs (carcinogenic) (as benzo(a)pyrene)	2.73E-03
Tetrachloroethene	4.16E-02
1,1,2-Trichloroethane	7.08E-03
Trichloroethene	9.11E-02
Vinyl chloride	4.87E-04
<u>Inorganics</u>	
Arsenic	2.81E-02
Beryllium	1.78E-02
Cadmium	1.62E-01
Chromium (as VI)	2.40E-02
Nickel	1.22E+00

<sup>1</sup> Based on the additivity of the risk of all 17 carcinogens, each of which poses a  $10^{-7}$  cancer risk.

dual carcinogens would result in a total (additive) cancer risk of 1.7 in one million ( $1.7E-06$ ) for all contaminants through all exposure routes combined. Because the target clean-up goal is a  $10^{-6}$  total cancer risk, the  $10^{-7}$  risk soil concentrations were divided by 1.7. The soil concentrations which result in a total (additive) cancer risk of  $10^{-6}$  are presented in Table 5-13.

## 5.2 DETERMINATION OF CLEAN-UP LEVELS BASED ON THE NONCARCINOGENIC RISK POSED BY ALL SITE CONTAMINANTS

### 5.2.1 General Approach

This subsection presents the general approach of the model used in determining target clean-up levels for soil based on potential noncarcinogenic risk. The approach based on noncarcinogenic risk parallels the approach used for determining clean-up levels based on carcinogenic risk (see Subsection 5.1). The details of the methodology are presented in Subsections 5.2.2 and 5.2.3.

For noncarcinogenic risk the clean-up goal was a hazard index (HI) of one. The hazard index is the sum of the hazard quotients (i.e., the estimated daily intake (dose) to reference dose ratios) for all of the contaminants through all exposure routes combined. In assessing noncarcinogenic risk, a hazard index of one or less is considered to be acceptable. If the hazard index exceeds one, it indicates that there might be the potential for adverse noncarcinogenic health effects occurring. Unlike the method used to evaluate the potential for carcinogenic toxicity, the hazard index does not indicate the probability of adverse health effects occurring, but is used as a benchmark for determining where there is a potential concern. The hazard index approach for evaluating noncarcinogenic risk was developed by the U.S. EPA (EPA, 1989d). Theoretically, only the hazard quotients for chemicals that produce the same toxicological endpoint by the same mechanism should be added in

Table 5-13

Soil Concentrations Resulting in a  $1.0 \times 10^{-6}$   
Total Cancer Risk from All Contaminants  
Through All Exposure Routes Combined

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Bis(2-ethylhexyl)phthalate	1.89E-01
Carbon tetrachloride	2.83E-03
Chloroform	3.65E-02
1,1-Dichloroethane	2.93E-03
1,2-Dichloroethane	1.71E-03
1,1-Dichloroethene	9.05E-04
Methylene chloride	1.44E-02
PAHs (carcinogenic) (as benzo(a)pyrene)	1.61E-03
Tetrachloroethene	2.45E-02
1,1,2-Trichloroethane	4.17E-03
Trichloroethene	5.36E-02
Vinyl chloride	2.86E-04
<u>Inorganics</u>	
Arsenic	1.65E-02
Beryllium	1.05E-02
Cadmium	9.54E-02
Chromium (as VI)	1.41E-02
Nickel	7.16E-01

<sup>1</sup> Based on the additivity of the risk of all 17 carcinogens, each of which poses a cancer risk of approximately  $5.88 \times 10^{-8}$ .



calculating a hazard index. However, to simplify the calculations, it was assumed that the hazard quotients for all of the site contaminants are additive. The determination of clean-up levels based on the segregation of contaminants according to their mechanism of toxic action is briefly discussed in Subsection 5.4.3.

To determine soil clean-up levels based on noncarcinogenic risk, each contaminant was allowed a soil clean-up level which would result in the sum of the hazard quotients for all exposure routes being equal to  $1/35$ . Because there are 35 site contaminants, this would ensure that the hazard index would not exceed one. Soil contaminant concentrations were first determined for each exposure route based on a hazard quotient of  $1/n$ , where  $n$  is the number of contaminants being evaluated for the exposure route. The soil concentrations based on individual exposure routes were then used to determine the clean-up level based on all exposure routes combined.

#### **5.2.2 Determination of Clean-up Levels Based on Noncarcinogenic Risk through Individual Exposure Routes**

This subsection presents the mathematical models that were used to determine soil concentrations for individual exposure routes based on noncarcinogenic health risk. The models are presented in tabulated form. Each table includes the definition of the variables for the exposure route and the assumptions used in the model. Additional information regarding the assumptions are presented in the text. The derivation of the models is presented in Appendix E, Section E.2.

The exposure factors that were used for the receptor (i.e., resident) were those for a child aged 1-6 years. In a risk assessment, hazard indices are calculated separately for children and adults. However, unlike the approach used to evaluate carcinogenic risk, in which childhood and adult risks are added to

give a lifetime cancer risk (see Subsection 5.1.2), childhood and adult hazard indices are not additive (i.e., they are not combined to give the equivalent of a lifetime noncarcinogenic risk). It is assumed in evaluating the potential for noncarcinogenic health effects, that if a hazard index exceeds one at any period in an individual's lifetime (e.g., childhood or adulthood), there may be the potential at that time for adverse health effects occurring. As a result of their smaller body size and behavior patterns (e.g., tendency to put objects in their mouth), young children usually receive a larger intake of contaminants per unit body weight (i.e., dose) than adults. Because a child's intake is expected to be greater than an adult's, and the same reference doses are used to evaluate both the child and adult, the child's hazard index is likely to be higher than that of the adult. By basing the clean-up levels on a child's intake, the adult as well as the child will be protected.

With the exception of the receptor-specific factors (i.e., child versus adult), the assumptions that were made for each exposure route were the same as those used in the models based on carcinogenic risk. The body weight for the child which is used in each model was calculated based on the average (50 percentile) body weights reported for male and female children aged 1 to 6 years (Anderson et al., 1985).

#### 5.2.2.1 Incidental Soil Ingestion

The model and assumptions that were used to calculate soil concentrations based on noncarcinogenic risk posed by incidental soil ingestion are presented in Table 5-14. The exposure period was assumed to be the same as that for the adult (i.e., 40 weeks/year). The soil concentrations calculated on the basis of noncarcinogenic risk through incidental soil ingestion are presented in Table 5-15.

Table 5-14

**Model for Determining the Soil Concentration  
of a Contaminant Representing Protection from  
Noncarcinogenic Risk Posed by Incidental Soil Ingestion**

---


$$C_{\text{soil}} = \frac{\text{ORFD} \times \text{HQ} \times \text{BW}}{\text{SIR} \times \text{W/Y} \times \text{CF}}$$


---

Variables:

$C_{\text{soil}}$	=	Contaminant concentration in the soil (mg/kg)
ORFD	=	Oral reference dose (mg/kg/day)
HQ	=	Hazard quotient (unitless)
BW	=	Body weight (kg)
SIR	=	Soil ingestion rate (mg/day)
W/Y	=	Number of weeks exposed per year (weeks/year)
CF	=	Conversion factor ( $10^{-6}$ kg/mg; 1 year/52 weeks)

---

Assumptions:

- (1) The oral reference dose (ORFD) for each contaminant is presented in Table 4-5.
- (2) The hazard quotient (HQ) is 1/35.
- (3) The body weight (BW) of an average child aged 1-6 years is 16 kg (Anderson et al., 1985).
- (4) The soil ingestion rate (SIR) of a child is 200 mg/day (EPA, 1989b).
- (5) An individual is exposed 40 weeks per year (W/Y).

Table 5-15

Soil Concentrations Representing Protection from  
Noncarcinogenic Risk Posed by Incidental Soil Ingestion

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Acetone	2.97E+02
Bis(2-ethylhexyl)phthalate	5.94E+01
2-Butanone	1.49E+02
Carbon tetrachloride	2.08E+00
Chloroform	2.97E+01
1,1-Dichloroethane	2.97E+02
1,2-Dichloroethane	2.20E+01
1,1-Dichloroethene	2.67E+01
Ethylbenzene	2.97E+02
Methylene chloride	1.78E+02
PAHs (total)	1.19E-01
Tetrachloroethene	2.97E+01
Toluene	8.91E+02
1,1,1-Trichloroethane	2.67E+02
1,1,2-Trichloroethane	1.19E+01
Trichloroethene	2.20E+01
Vinyl chloride	3.86E+00
<u>Inorganics</u>	
Arsenic	2.97E+00
Barium	1.49E+02
Beryllium	1.49E+01
Cadmium	2.97E+00
Chromium (as VI)	1.49E+01
Cyanide	5.94E+01
Iron	8.91E+03
Lead	4.16E-01
Lithium	7.13E+01
Mercury	8.91E-01
Nickel	5.94E+01
Nitrate-Nitrite	2.97E+02
Selenium	8.91E+00
Strontium	4.75E+00
Sulfate	2.11E+04
Thallium	2.08E-01
Uranium	1.78E+00
Vanadium	2.08E+01

#### 5.2.2.2 Vegetable Ingestion

The model and assumptions used in calculating soil concentrations based on (root) vegetable ingestion are presented in Table 5-16. A wet weight root vegetable ingestion rate was calculated based on an average dry weight root vegetable ingestion rate for a 2-year old (EPA, 1986b), adjusted for a moisture content of 88.2 percent (based on carrots) (Baes et al., 1984).

The soil contaminant concentrations that were calculated based on noncarcinogenic risk posed through vegetable ingestion are presented in Table 5-17.

#### 5.2.2.3 Dermal Contact With Soil

The model and assumptions that were used to calculate soil concentrations based on noncarcinogenic risk posed by dermal contact with soil are presented in Table 5-18. The hand and arm surface area for the child was calculated based on data presented in Anderson et al. (1985) for male and female children aged two through seven years. The soil contaminant concentrations that were calculated on the basis of noncarcinogenic risk posed by dermal contact with soil are presented in Table 5-19.

#### 5.2.2.4 Inhalation of Airborne Contaminated Soil

The model and assumptions that were used to calculate soil concentrations based on noncarcinogenic risk through the inhalation of airborne contaminated soil are presented in Table 5-20. Because climatic region 3 factors were shown in Subsection 5.1.2.4 to result in the most conservative soil concentrations, and because the most conservative soil concentrations are used in determining final clean-up levels, climatic 3 factors were used in the calculations. The calculated soil concentrations based on the inhalation of contaminated soil are presented in Table 5-21.

Table 5-16

**Model for Determining the Soil Concentration  
of a Contaminant Representing Protection from  
Noncarcinogenic Risk Posed by Vegetable Ingestion**

---


$$C_{\text{soil}} = \frac{\text{ORFD} \times \text{HQ} \times \text{BW}}{\text{VIR} \times \text{FR} \times \text{RUF} \times \text{CF}}$$


---

**Variables:**

$C_{\text{soil}}$	=	Contaminant concentration in the soil (mg/kg).
ORFD	=	Oral reference dose (mg/kg/day).
HQ	=	Hazard quotient (unitless).
BW	=	Body weight (kg).
VIR	=	Root vegetable ingestion rate (g/day).
FR	=	Fraction of vegetables that are homegrown (unitless).
RUF	=	Root uptake factor (unitless).
CF	=	Conversion factor ( $10^{-3}$ kg/g).

---

**Assumptions:**

- (1) The oral reference dose (ORFD) for each contaminant is presented in Table 4-5.
- (2) The hazard quotient (HQ) is 1/35.
- (3) The body weight (BW) of an average child aged 1-6 years is 16 kg (Anderson et al., 1985).
- (4) The root vegetable ingestion rate (VIR) for a child is 6.3 g/day (see text, Subsection 5.2.2.2).
- (5) The fraction of vegetables that is homegrown (FR) is 0.50 (see text, Subsection 5.2.2.2).
- (6) The root uptake factor (RUF) for each contaminant is presented in Appendix F, Table F-2.

Table 5-17

Soil Concentrations Representing Protection from  
Noncarcinogenic Risk Posed by Vegetable Ingestion

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Acetone	9.51E-01
Bis(2-ethylhexyl)phthalate	1.54E+01
2-Butanone	9.41E-01
Carbon tetrachloride	6.85E-02
Chloroform	6.20E-01
1,1-Dichloroethane	7.06E+00
1,2-Dichloroethane	3.04E-01
1,1-Dichloroethene	1.32E+00
Ethylbenzene	4.50E+01
Methylene chloride	1.71E+00
PAHs (total)	5.70E-01
Tetrachloroethene	3.43E+00
Toluene	7.04E+01
1,1,1-Trichloroethane	1.48E+01
1,1,2-Trichloroethane	2.52E-01
Trichloroethene	1.18E+00
Vinyl chloride	2.30E-01
<u>Inorganics</u>	
Arsenic	2.05E+02
Beryllium	4.10E+03
Barium	4.10E+03
Cadmium	8.20E+00
Chromium (as VI)	1.37E+03
Cyanide	3.51E-01
Iron	3.69E+06
Lead	1.91E+01
Lithium	7.38E+03
Mercury	1.84E+00
Nickel	4.10E+02
Nitrate-Nitrite	4.10E+00
Selenium	1.48E+02
Strontium	7.87E+00
Sulfate	5.82E+03
Thallium	2.15E+02
Uranium	1.84E+02
Vanadium	2.87E+03

Table 5-18

**Model for Determining the Soil Concentration  
of a Contaminant Representing Protection from  
Noncarcinogenic Risk Posed by Dermal Contact with Soil**

$$C_{\text{soil}} = \frac{\text{DRFD} \times \text{HQ} \times \text{BW}}{\text{ESA} \times \text{SA} \times \text{AF} \times \text{W/Y} \times \text{CF}}$$

**Variables:**

$C_{\text{soil}}$	=	Contaminant concentration in the soil (mg/kg).
DRFD	=	Dermal reference dose (mg/kg/day).
HQ	=	Hazard quotient (unitless).
BW	=	Body weight (kg).
ESA	=	Exposed skin surface area (cm <sup>2</sup> /day).
SA	=	Skin adherence factor (mg/cm <sup>2</sup> ).
AF	=	Dermal absorption factor (unitless).
W/Y	=	Number of weeks exposed per year (weeks/year).
CF	=	Conversion factors (10 <sup>-6</sup> kg/mg; 1 year/52 weeks).

**Assumptions:**

- (1) The dermal reference dose (DRFD) for each contaminant is presented in Table 4-5.
- (2) The hazard quotient (HQ) is 1/19.
- (3) The body weight (BW) of an average child aged 1-6 years is 16 kg (Anderson et al., 1985).
- (4) The exposed skin surface area (ESA) is 1,350 cm<sup>2</sup>/day (see text, Subsection 5.2.2.3).
- (5) The skin adherence factor (SA) is 1.45 mg/cm<sup>2</sup> (See text, Subsection 5.2.2.3).
- (6) The dermal absorption factor (AF) is 0.02 (see text, Subsection 5.1.2.3).
- (7) An individual is exposed 40 weeks per year (W/Y).



Table 5-19

Soil Concentrations Representing Protection from  
Noncarcinogenic Risk Posed by Dermal Contact with Soil

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Acetone	2.80E+03
Bis(2-ethylhexyl)phthalate	1.43E+02
2-Butanone	1.40E+03
Carbon tetrachloride	1.96E+01
Chloroform	2.80E+02
1,1-Dichloroethane	2.80E+03
1,2-Dichloroethane	2.07E+02
1,1-Dichloroethene	2.52E+02
Ethylbenzene	2.80E+03
Methylene chloride	1.68E+03
PAHs (total)	1.43E+01
Tetrachloroethene	2.80E+02
Toluene	8.39E+03
1,1,1-Trichloroethane	2.52E+03
1,1,2-Trichloroethane	1.12E+02
Trichloroethene	2.07E+02
Vinyl chloride	3.64E+01
<u>Inorganics</u>	
Arsenic	NA
Barium	NA
Beryllium	NA
Cadmium	NA
Chromium (as VI)	NA
Cyanide	1.43E+02
Iron	NA
Lead	NA
Lithium	NA
Mercury	2.80E-01
Nickel	NA
Nitrate-Nitrite	NA
Selenium	NA
Strontium	NA
Sulfate	NA
Thallium	NA
Uranium	NA
Vanadium	NA

NA = Not applicable. Chemical is not of concern through this exposure route.

Table 5-20

Model for Determining the Soil Concentration  
of a Contaminant Representing Protection from  
Noncarcinogenic Risk Posed by the Inhalation  
of Airborne Contaminated Soil

$$C_{\text{soil}} = \frac{\text{IRFD} \times \text{HQ} \times \text{BW} \times \text{CRF}}{\text{IR} \times F_1 \times \text{PM}_{10}\text{EF} \times \text{ASP} \times \text{CF}}$$

Variables:

$C_{\text{soil}}$	=	Contaminant concentration in the soil (mg/kg).
IRFD	=	Inhalation reference dose (mg/kg/day).
HQ	=	Hazard quotient (unitless).
BW	=	Body weight (kg).
CRF	=	Climatic region factor (unitless).
IR	=	Inhalation rate ( $\text{m}^3/\text{day}$ ).
$F_1$	=	Unscaled concentration due to a unit erosion rate ( $\text{ug}/\text{m}^3$ )/( $\text{g}/\text{sec}$ ).
$\text{PM}_{10}\text{EF}$	=	$\text{PM}_{10}$ (respirable size particles) emission factor ( $\text{mg}/\text{m}^2/\text{hr}$ ).
ASP	=	Area of the solar ponds ( $\text{m}^2$ ).
CF	=	Conversion factors ( $10^{-3}$ g/mg; $10^{-6}$ kg/mg; $10^{-3}$ mg/ug; 1 hr/3,600 sec).

Assumptions:

- (1) The inhalation reference dose (IRFD) for each contaminant is presented in Table 4-5.
- (2) The hazard quotient (HQ) is 1/35.
- (3) The body weight (BW) of a average child aged 1-6 years is 16 kg (Anderson et al., 1985).
- (4) The climatic region factor (CRF) is 0.0396 for climatic region 3 (EPA, 1985b).
- (5) The inhalation rate (IR) of a child is  $15 \text{ m}^3/\text{day}$  (NCRP, 1984).
- (6)  $F_1$  is 4.789 for climatic region 3.
- (7) The  $\text{PM}_{10}$  emission factor ( $\text{PM}_{10}\text{EF}$ ) is  $4,097 \text{ mg}/\text{m}^2/\text{hr}$ . (The  $\text{PM}_{10}\text{EF}$  is derived in Appendix G)
- (8) The area of the solar ponds (ASP) is  $25,086 \text{ m}^2$  (estimated).

Table 5-21

Soil Concentrations Representing Protection from  
Noncarcinogenic Risk Posed by the Inhalation of Airborne  
Contaminated Soil

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Acetone	2.38E+05
Bis(2-ethylhexyl)phthalate	6.75E+02
2-Butanone	1.19E+04
Carbon tetrachloride	4.24E+03
Chloroform	6.62E+03
1,1-Dichloroethane	1.32E+04
1,2-Dichloroethane	5.43E+03
1,1-Dichloroethene	2.65E+03
Ethylbenzene	5.83E+04
Methylene chloride	1.14E+05
PAHs (total)	6.75E+01
Tetrachloroethene	4.63E+04
Toluene	7.55E+04
1,1,1-Trichloroethane	3.97E+04
1,1,2-Trichloroethane	7.41E+03
Trichloroethene	3.57E+04
Vinyl chloride	1.32E+03
<u>Inorganics</u>	
Arsenic	2.65E+01
Barium	1.32E+01
Beryllium	2.65E-01
Cadmium	6.75E+00
Chromium (as VI)	6.75E+00
Cyanide	6.75E+02
Iron	1.32E+02
Lead	1.99E+01
Lithium	1.32E+01
Mercury	1.32E+00
Nickel	1.32E+01
Nitrate-Nitrite	1.35E+03
Selenium	2.65E+01
Strontium	1.32E+03
Sulfate	1.35E+03
Thallium	1.32E+01
Uranium	1.35E+03
Vanadium	6.75E+00

#### 5.2.2.5 Inhalation of Vapors

The model and assumptions that were used to calculate soil concentrations based on noncarcinogenic risk through the inhalation of vapors are presented in Table 5-22. Because the X/Q factor for climatic region 3 was shown to result in the most conservative soil concentrations (see Subsection 5.1.2.5), only the X/Q factor for region 3 was used in the calculations. The calculated soil concentrations are presented in Table 5-23.

#### 5.2.3 Determination of Soil Concentration Based on Non-Carcinogenic Risk Through All Exposure Routes Combined

The soil concentration of each site contaminant that would contribute 1/35 of a hazard index of one through all exposure routes combined was calculated using the equation of Rosenblatt et al. (1982). The multiroute soil concentrations are based on the soil concentrations calculated for individual exposure routes in Subsection 5.2.2.

$$CCS-NC = 1 / (1/C_{SI} + 1/C_{VI} + 1/C_{DC} + 1/C_{IS} + 1/C_{IV})$$

where,

CCS-NC = The contaminant concentration in soil resulting in the sum of the hazard quotients for all exposure routes being equal to 1/35 (mg/kg).

$C_{SI}$  = The contaminant concentration in soil resulting in a hazard quotient of 1/35 based on incidental soil ingestion (mg/kg).

$C_{VI}$  = The contaminant concentration in soil resulting in a hazard quotient of 1/35 based on incidental soil ingestion (mg/kg).

Table 5-22

**Model for Determining the Soil Concentration of a  
Contaminant Representing Protection from Noncarcinogenic  
Risk Posed by the Inhalation of Vapors**

$$C_{\text{soil}} = \frac{\text{IRFD} \times \text{HQ} \times \text{BW} \times \text{T}}{\text{IR} \times P_{\text{soil}} \times \text{ASP} \times F_a \times L \times X/Q \times \text{CF}}$$

**Variables:**

$C_{\text{soil}}$	=	Contaminant concentration in the soil (mg/kg).
IRFD	=	Inhalation reference dose (mg/kg/day).
HQ	=	Hazard quotient (unitless).
BW	=	Body weight (kg).
T	=	Time after the waste is applied to the soil (sec).
IR	=	Inhalation rate ( $\text{m}^3/\text{day}$ ).
$P_{\text{soil}}$	=	Density of the soil ( $\text{g}/\text{cm}^3$ ).
ASP	=	Area of the solar ponds ( $\text{m}^2$ ).
$F_a$	=	Fraction of the contaminant released to the air during 70 years (unitless).
L	=	Depth of contaminated soil (cm).
X/Q	=	Contaminant concentration in air/emissions rate ( $\text{ug}/\text{m}^3$ )/( $\text{g}/\text{sec}$ ).
CF	=	Conversion factors ( $10^4 \text{ cm}^2/\text{m}^2$ ; $10^{-6} (\text{g}/\text{g})/(\text{mg}/\text{kg})$ ; $10^{-3} \text{ mg}/\text{ug}$ ).

**Assumptions:**

- (1) The inhalation reference dose (IRFD) for each contaminant is presented in Table 4-5.
- (2) The hazard quotient (HQ) is 1/17.
- (3) The body weight (BW) of a average child aged 1-6 years is 16 kg (Anderson et al., 1985).
- (4) The time after the waste is applied to the soil (T) is equal to a 70 year lifetime,  $2.21 \times 10^9$  sec.
- (5) The inhalation rate (IR) of a child is  $15 \text{ m}^3/\text{day}$  (NCRP, 1984).
- (6) The density of the soil ( $P_{\text{soil}}$ ) is the density reported for packed dry earth,  $1.5 \text{ g}/\text{cm}^3$ .
- (7) The area of the solar ponds (ASP) is  $25,086 \text{ m}^2$  (estimated).
- (8) The fraction of the compound released to the air during 70 years ( $F_a$ ) is presented in Appendix Table H-1.
- (9) The depth of contaminated soil (L) is 121 cm (estimated).
- (10) The contaminant concentration in air/emissions rate (X/Q) is approximately  $4.789 (\text{ug}/\text{m}^3)/(\text{g}/\text{s})$  for climatic region 3 (EPA, 1985b).

Table 5-23

Contaminant Concentrations in Soil Representing  
Protection from Noncarcinogenic Risk  
Posed by the Inhalation of Vapors

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Acetone	1.69E+06
Bis(2-ethylhexyl)phthalate	2.94E+07
2-Butanone	8.63E+04
Carbon tetrachloride	3.04E+04
Chloroform	4.71E+04
1,1-Dichloroethane	9.44E+04
1,2-Dichloroethane	3.89E+04
1,1-Dichloroethene	1.88E+04
Ethylbenzene	4.68E+05
Methylene chloride	8.10E+05
PAHs (total)	4.98E+04
Tetrachloroethene	3.50E+05
Toluene	5.68E+05
1,1,1-Trichloroethane	2.84E+05
1,1,2-Trichloroethane	5.50E+04
Trichloroethene	2.58E+05
Vinyl chloride	9.41E+03

$C_{DC}$  = The contaminant concentration in soil resulting in a hazard quotient of 1/19 based on dermal contact with soil (mg/kg).

$C_{IS}$  = The contaminant concentration in soil resulting in a hazard quotient of 1/35 based on the inhalation of airborne contaminated soil (mg/kg).

$C_{IV}$  = The contaminant concentration in soil resulting in a hazard quotient of 1/17 based on the inhalation of vapors.

The soil concentration of each contaminant which results in the sum of the hazard quotients for all exposure routes being equal to 1/35 is presented in Table 5-24. The soil concentrations for the individual contaminants results in a hazard index (i.e., the sum of the hazard quotients for all contaminants through all exposure routes) of one.

### **5.3 TARGET CLEAN-UP LEVELS IN SOIL BASED ON THE PRESENCE OF ALL SITE CONTAMINANTS**

The final target soil clean-up levels are presented for the site contaminants in Table 5-25. For the carcinogens, clean-up levels were calculated based on both carcinogenic and noncarcinogenic risk. The lowest (i.e., most conservative) clean-up level that was calculated for each carcinogen was considered to be the final clean-up level; in all cases, the lowest clean-up level for these chemicals was the one calculated based on carcinogenic risk.

### **5.4 DETERMINATION OF LOCATION-SPECIFIC SOIL CLEAN-UP LEVELS**

Because sampling data were not available for the soils beneath the solar ponds, clean-up levels were derived for these soils in Subsections 5.1 through 5.3 based on all possible site

Table 5-24

Contaminant Concentrations in Soil Representing  
Protection from Noncarcinogenic Risk Through all  
Exposure Routes Combined<sup>1</sup>

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Acetone	9.47E-01
Bis(2-ethylhexyl)phthalate	1.11E+01
2-Butanone	9.34E-01
Carbon tetrachloride	6.61E-02
Chloroform	6.06E-01
1,1-Dichloroethane	6.88E+00
1,2-Dichloroethane	2.99E-01
1,1-Dichloroethene	1.25E+00
Ethylbenzene	3.85E+01
Methylene chloride	1.69E+00
PAHs (total)	9.75E-02
Tetrachloroethene	3.04E+00
Toluene	6.47E+01
1,1,1-Trichloroethane	1.39E+01
1,1,2-Trichloroethane	2.46E-01
Trichloroethene	1.11E+00
Vinyl chloride	2.16E-01
<u>Inorganics</u>	
Arsenic	2.64E+00
Barium	1.21E+01
Beryllium	2.60E-01
Cadmium	1.65E+00
Chromium (as VI)	4.63E+00
Cyanide	3.48E-01
Iron	1.30E+02
Lead	3.99E-01
Lithium	1.12E+01
Mercury	1.67E-01
Nickel	1.05E+01
Nitrate-Nitrite	4.03E+00
Selenium	6.38E+00
Strontium	2.96E+00
Sulfate	1.04E+03
Thallium	2.05E-01
Uranium	1.76E+00
Vanadium	5.09E+00

<sup>1</sup>Sum of the daily intake:reference dose ratios for each contaminant (i.e., hazard quotients) is equal to 1/35, resulting in a hazard index of one.



Table 5-25

Final Target Clean-up Levels for Soil  
Based on All Site Contaminants

Chemical	Soil Concentration (mg/kg)
<u>Organics</u>	
Acetone	9.47E-01
Bis(2-ethylhexyl)phthalate	1.89E-01(c)
2-Butanone	9.34E-01
Carbon tetrachloride	2.83E-03(c)
Chloroform	3.65E-02(c)
1,1-Dichloroethane	2.93E-03(c)
1,2-Dichloroethane	1.71E-03(c)
1,1-Dichloroethene	9.05E-04(c)
Ethylbenzene	3.85E+01
Methylene chloride	1.44E-02(c)
PAHs (total)	1.61E-03(c)
Tetrachloroethene	2.45E-02(c)
Toluene	6.47E+01
1,1,1-Trichloroethane	1.39E+01
1,1,2-Trichloroethane	4.17E-03(c)
Trichloroethene	5.36E-02(c)
Vinyl chloride	2.86E-04(c)
<u>Inorganics</u>	
Arsenic	1.65E-02(c)
Barium	1.21E+01
Beryllium	1.05E-02(c)
Cadmium	9.54E-02(c)
Chromium (as VI)	1.41E-02(c)
Cyanide	3.48E-01
Iron	1.30E+02
Lead	3.99E-01
Lithium	1.12E+01
Mercury	1.67E-01
Nickel	7.16E-01(c)
Nitrate-Nitrite	4.03E+00
Selenium	6.38E+00
Strontium	2.96E+00
Sulfate	1.04E+03
Thallium	2.05E-01
Uranium	1.76E+00 <sup>1</sup>
Vanadium	5.09E+00

(C) Final clean-up level is based on carcinogenic risk.

<sup>1</sup> Tentative clean-up level. Clean-up level based on radio-toxicity may be lower.

contaminants. However, the available sampling data indicate that not all of the organic site contaminants are present throughout the soils surrounding the ponds and that not all of the inorganic contaminants are present above background at all site locations. Because target clean-up levels are based on the assumption of the additivity of toxic effects, clean-up levels are dependent on the number of contaminants present. Therefore, location-specific clean-up levels may need to be calculated for the soils surrounding the ponds.

The contaminants for each site location should be chosen using the same approach as that used to determine the site contaminants for the site as a whole. The approach for selecting site contaminants was presented in Section 2.0.

#### **5.4.1 Location-Specific Clean-up Levels for Carcinogens**

Clean-up levels can be derived for the carcinogens at each site location by adjusting the  $10^{-7}$  risk soil concentrations that were calculated based on all of the site contaminants (Table 5-12). The clean-up levels for the carcinogens which would result in a total  $10^{-6}$  cancer risk at any given location can be calculated using the following equation:

$$(5.4-1) \quad C_{\text{CSL}} = \frac{\text{TCL-C} \times 10}{\text{\#CAR-SL}}$$

where,

$C_{\text{CSL}}$  = The soil clean-up level for a carcinogen at a specific site location.

$\text{TCL-C}$  = The contaminant concentration in soil posing a  $10^{-7}$  cancer risk (mg/kg) (from Table 5-12).

$\text{\#CAR-SL}$  = The number of carcinogens at the site location.

#### 5.4.2 Location-Specific Clean-up Levels for Noncarcinogens

Clean-up levels based on noncarcinogenic risk need to be calculated only for the noncarcinogens, since previous calculations (Subsections 5.1 and 5.2) indicated that for the carcinogenic site contaminants, the limiting factor in determining clean-up levels is carcinogenic risk. The clean-up level for each noncarcinogen can be calculated using the following equation:

$$(5.4-2) \quad C_{NCSL} = \frac{TCL-NC \times \#C-SITE}{\#C-SL}$$

where,

$C_{NCSL}$  = The soil clean-up level for a noncarcinogen at a specific site location (mg/kg)

$CCS-NC$  = The soil concentration determined for the chemical based on the noncarcinogenic risk posed by all contaminants (mg/kg) (from Table 5-24 or 5-25).

$\#C-SITE$  = The number of contaminants for the entire site (i.e., 35).

$\#C-SL$  = The total number of site contaminants at the site location

As an example, a theoretical site location can be assumed at which the following are considered to be site contaminants: arsenic, cadmium, chromium, lithium, nickel, and nitrate. Based on their frequency of detection above background, and/or reported concentrations above background (see Appendix B), these inorganics are among the site contaminants that are most

likely to be identified as location-specific contaminants in soils surrounding the ponds. Of these chemicals, clean-up levels for arsenic, cadmium, chromium, and nickel would be based on carcinogenic risk and those for lithium and nitrate on non-carcinogenic risk. The clean-up levels for these contaminants at the theoretical site location, calculated using equations 5.4-1 and 5.4-2, are presented in Table 5-26. The cleanup levels that were calculated for these contaminants based on all site contaminants combined are also presented for comparison.

#### 5.4.3 Assumptions and Uncertainties

The approach used to derive clean-up levels at each site-specific location should be viewed as an initial approach which can then be modified, depending on the sampling results at that location. The approach is based on the additivity of the risk of individual chemicals, each of which is allowed the same weighted risk (i.e., either the same fraction of the hazard index or the same cancer risk). Technically, however, there are innumerable combinations of soil concentrations which could result in goals of a hazard index of one and a lifetime total cancer risk of  $10^{-6}$  (i.e., if the concentration of one contaminant is lowered, the concentration(s) of another contaminant(s) may be raised without changing the overall risk). For example, if the sampling results indicate that a particular contaminant is present at a given location at a concentration that is below the calculated clean-up concentration, the clean-up concentrations of the other contaminants may be raised accordingly.

At locations at which there are both carcinogenic and noncarcinogenic contaminants, the clean-up levels for the noncarcinogens can be higher than those that would be calculated using equation (5.4-2). The clean-up levels for the carcinogens will be based on carcinogenic risk, because the cancer risk-based clean-up levels are lower than those based on noncarcinogenic

Table 5-26

**Comparison of Target Clean-up Levels for Contaminants  
at a Theoretical Site Location with Target  
Clean-up Levels Based on All Site Contaminants**

	Soil Concentration (mg/kg)	
	<u>Theoretical Site Location<sup>1</sup></u>	<u>Based on All Site Contaminants<sup>2</sup></u>
Arsenic	7.03E-02(c)	1.65E-02(c)
Cadmium	4.05E-01(c)	9.54E-02(c)
Chromium	6.00E-02(c)	1.41E-02(c)
Lithium	6.53E+01	1.12E+01
Nickel	3.05E+00(c)	7.16E-01(c)
Nitrate-Nitrite	2.35E+01	4.03E+00

- <sup>1</sup> Calculated for a theoretical site location at which only the six listed chemicals are identified as site contaminants.
- <sup>2</sup> Site location at which all 35 site contaminants are assumed to be present (from Table 5-24).
- (c) Clean-up level is based on carcinogenic risk.

risk (see Subsection 5.3). However, the clean-up levels for the noncarcinogens take into account the noncarcinogenic risk posed by the carcinogens. Because the carcinogens will have to be cleaned up to lower levels than those based on noncarcinogenic risk, the clean-up levels for the noncarcinogens can then be raised proportionately.

Finally, as previously indicated in Subsection 5.2.1, the assumption of additivity in determining the potential for noncarcinogenic health risks is most appropriately applied to chemicals that produce the same toxic effect by the same mechanism. If the contaminants at a given location have different noncarcinogenic toxic effects, it may be possible to raise the target clean-up levels by segregating the contaminants according to their mechanism of toxic action and then determining clean-up levels for the chemicals within each group.

## SECTION 6.0

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<sup>1</sup> The references include those for the text and the appendices.

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**SECTION 7.0  
APPENDICES**

**APPENDIX A****APPROACH TO CALCULATING THE UPPER LIMIT OF THE TOLERANCE  
INTERVAL FOR THE BACKGROUND SOILS DATA**

In order to develop representative background data, samples were collected from the surficial and bedrock soils in the plant buffer zone to the southeast and northwest of the plant. The primary determinant for use of the appropriate statistical method for comparison of background and non-background chemical concentrations is the percentage of values above analytical detection limits. If there are less than 10 percent detects for a particular parameter, tolerance intervals based on the Poisson distribution are appropriate; if greater than 10 percent and less than 50 percent detects occur, a test of proportions is appropriate; and if greater than 50 percent detects are encountered, tolerance intervals based on a normal distribution or analysis of variance (ANOVA) are appropriate (EPA, 1989e). Tolerance intervals based on a normal distribution were calculated when greater than 50 percent detects were encountered.

Tolerance intervals define a range that contains at least "p" percent of a population with "P" percent probability (level of confidence) (i.e., upon repeated sampling, "P" percent of the calculated intervals will contain "p" percent of the population). Tolerance intervals answer the question: where do most of the observations lie?

For the tolerance interval to be useful in decision making, both "p" and "P" are chosen to be large, in this case,  $p = 0.95$  and  $P = 0.95$ . An on-site chemical concentration that lies outside of this interval may represent a contaminant released from the site.

A tolerance interval is either one-sided or two-sided. A two-sided tolerance interval is appropriate whenever a concentration either larger or smaller than background may be associated with a contaminant release, e.g., pH. In the case of soils, one-sided tolerance intervals are appropriate where an increase over background concentrations are indicative of releases. A two-sided interval is defined by two limits ( $L_1$  and  $L_2$ ) where a proportion "p" of the population is contained between the limits  $L_1$  and  $L_2$  with probability "P". An upper (or lower) one-sided tolerance limit is defined so that "P" percent of the population is less than (or greater than) the upper limit  $L_2$ .

The upper limit tolerance interval for the background soil data was calculated using the equation:

$$L_2 = \bar{X} + Ks$$

where,

- $L_2$  = upper tolerance interval
- $\bar{X}$  = mean of the sample data of sample size n
- s = standard deviation of the sample data
- K = the normal tolerance factor (dependent on p, P, and n)

"K" values were obtained from Table A-1.

Some inorganic constituents will be undetected in background soil samples. Special procedures are thus needed to compute the mean and standard deviation of a population when a significant number of the observations are below the detection limit. A data set is termed censored when not detected (ND) observations are present in a data set, and some assumption must be made about the statistical distribution for the entire data set. A technique for calculation of the mean and standard deviation of

Table A-1

Tolerance Factors (K) for One-Sided Normal  
Tolerance Intervals for 95 Percent of the Population  
at 95 Percent Confidence

n	One-Sided
2	
3	7.655
4	5.145
5	4.202
6	3.707
7	3.399
8	3.188
9	3.031
10	2.911
11	2.815
12	2.736
13	2.670
14	2.614
15	2.566
16	2.523
17	2.486
18	2.453
19	2.423
20	2.396
21	2.371
22	2.350
23	2.329
24	2.309
25	2.292
26	2.278
27	2.263
28	2.249
29	2.234
30	2.220
35	2.166
40	2.126
45	2.092
50	2.065
60	2.017
80	1.962
100	1.924
200	1.836
500	1.763
1,000	1.727



such a data set was developed by Cohen and can be used if the data are normally distributed.

The Cohen procedure is as follows (Doctor, Gilbert, and Kinnison, 1986).

Let:

- n = The total number of observations for a constituent
- k = Number of actual measurements out of n (not NDs)
- $x_o$  = The detection limit of the constituent

Then:

- 1) Compute  $h = (n-k)/n$  (the proportion of measurements below the detection limit).
- 2) Compute  $x_u = (\text{sum of } x_i \text{ for } i = 1 \text{ to } k)/k$ .
- 3) Compute  $s^2_u = (\text{sum of } (x_i - x_u)^2 \text{ for } i = 1 \text{ to } k)/k$ .
- 4) Compute  $t = s^2_u / (x_u - x_o)^2$
- 5) Obtain an estimate of lambda (la) from Table A-2 using h and t.
- 6) Estimate the means and variance of the population from which the censored data set was drawn by computing:

$$X = x_u - la (x_u - x_o) \text{ and}$$

$$s = [s^2_u + la (x_u - x_o)^2]^{1/2}$$

Table A-2

Values of  $\lambda$  for Estimating the Mean and Variance of a Normal Distribution when ND Values are Present

$h$	$\tau$	.01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.15	.20	$h$	$\tau$
.00	.010100	.020400	.030902	.041583	.052507	.063627	.074953	.086488	.09824	.11020	.17342	.24268	.00	.00	
.05	.010551	.021294	.032225	.043350	.054670	.066189	.077909	.089834	.10197	.11431	.17935	.25033	.05	.05	
.10	.010950	.022082	.033398	.044902	.056596	.068483	.080568	.092852	.10534	.11804	.18479	.25741	.10	.10	
.15	.011310	.022798	.034466	.046318	.058356	.070586	.083009	.095629	.10845	.12148	.18985	.26405	.15	.15	
.20	.011642	.023459	.035453	.047629	.059990	.072539	.085280	.098216	.11135	.12469	.19460	.27031	.20	.20	
.25	.011952	.024076	.036377	.048858	.061522	.074372	.087413	.10065	.11408	.12772	.19910	.27626	.25	.25	
.30	.012243	.024658	.037249	.050018	.062969	.076106	.089433	.10295	.11667	.13059	.20338	.28193	.30	.30	
.35	.012520	.025211	.038077	.051120	.064345	.077756	.091355	.10515	.11914	.13333	.20747	.28737	.35	.35	
.40	.012784	.025738	.038866	.052173	.065660	.079332	.093193	.10725	.12150	.13595	.21139	.29260	.40	.40	
.45	.013036	.026243	.039624	.053182	.066921	.080845	.094958	.10926	.12377	.13847	.21517	.29765	.45	.45	
.50	.013279	.026728	.040352	.054153	.068135	.082301	.096657	.11121	.12595	.14090	.21882	.30253	.50	.50	
.55	.013513	.027196	.041054	.055089	.069306	.083708	.098298	.11308	.12806	.14325	.22235	.30725	.55	.55	
.60	.013739	.027649	.041733	.055995	.070439	.085068	.099887	.11490	.13011	.14552	.22578	.31184	.60	.60	
.65	.013958	.028087	.042391	.056874	.071538	.086388	.10143	.11666	.13209	.14773	.22910	.31630	.65	.65	
.70	.014171	.028513	.043030	.057726	.072605	.087670	.10292	.11837	.13402	.14987	.23234	.32065	.70	.70	
.75	.014378	.028927	.043632	.058556	.073643	.088917	.10438	.12004	.13590	.15196	.23550	.32489	.75	.75	
.80	.014579	.029330	.044258	.059364	.074655	.090133	.10580	.12167	.13773	.15400	.23858	.32903	.80	.80	
.85	.014775	.029723	.044848	.060153	.075642	.091319	.10719	.12325	.13952	.15599	.24158	.33307	.85	.85	
.90	.014967	.030107	.045425	.060923	.076606	.092477	.10854	.12480	.14126	.15793	.24452	.33703	.90	.90	
.95	.015154	.030483	.045989	.061676	.077549	.093611	.10987	.12632	.14297	.15983	.24740	.34091	.95	.95	
1.00	.015338	.030850	.046540	.062413	.078471	.094720	.11116	.12780	.14465	.16170	.25022	.34471	1.00	1.00	

$h$	$\tau$	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.80	.90	$h$	$\tau$
.00	.31862	.4021	.4941	.5961	.7096	.8368	.9808	1.145	1.336	1.561	2.176	3.283	.00	.00	
.05	.32793	.4130	.5066	.6101	.7252	.8540	.9994	1.166	1.358	1.585	2.203	3.314	.05	.05	
.10	.33662	.4233	.5184	.6234	.7400	.8703	1.017	1.185	1.379	1.608	2.229	3.345	.10	.10	
.15	.34480	.4330	.5296	.6361	.7542	.8860	1.035	1.204	1.400	1.630	2.255	3.376	.15	.15	
.20	.35255	.4422	.5403	.6483	.7678	.9012	1.051	1.222	1.419	1.651	2.280	3.405	.20	.20	
.25	.35993	.4510	.5506	.6600	.7810	.9158	1.067	1.240	1.439	1.672	2.305	3.435	.25	.25	
.30	.36700	.4595	.5604	.6713	.7937	.9300	1.083	1.257	1.457	1.693	2.329	3.464	.30	.30	
.35	.37379	.4676	.5699	.6821	.8060	.9437	1.098	1.274	1.476	1.713	2.353	3.492	.35	.35	
.40	.38033	.4755	.5791	.6927	.8169	.9570	1.113	1.290	1.494	1.732	2.376	3.520	.40	.40	
.45	.38665	.4831	.5880	.7029	.8295	.9700	1.127	1.306	1.511	1.751	2.399	3.547	.45	.45	
.50	.39276	.4904	.5967	.7129	.8408	.9826	1.141	1.321	1.528	1.770	2.421	3.575	.50	.50	
.55	.39870	.4976	.6051	.7225	.8517	.9950	1.155	1.337	1.545	1.788	2.443	3.601	.55	.55	
.60	.40447	.5045	.6133	.7320	.8625	1.007	1.169	1.351	1.561	1.806	2.465	3.628	.60	.60	
.65	.41008	.5114	.6213	.7412	.8729	1.019	1.182	1.366	1.557	1.824	2.486	3.654	.65	.65	
.70	.41555	.5180	.6291	.7502	.8832	1.030	1.195	1.380	1.593	1.841	2.507	3.679	.70	.70	
.75	.42090	.5245	.6367	.7590	.8932	1.042	1.207	1.394	1.608	1.858	2.528	3.705	.75	.75	
.80	.42612	.5308	.6441	.7676	.9031	1.053	1.220	1.408	1.624	1.875	2.548	3.730	.80	.80	
.85	.43122	.5370	.6515	.7761	.9127	1.064	1.232	1.422	1.639	1.892	2.568	3.754	.85	.85	
.90	.43622	.5430	.6586	.7844	.9222	1.074	1.244	1.435	1.653	1.908	2.588	3.779	.90	.90	
.95	.44112	.5490	.6656	.7925	.9314	1.085	1.255	1.448	1.668	1.924	2.607	3.803	.95	.95	
1.00	.44592	.5548	.6724	.8005	.9406	1.095	1.267	1.461	1.682	1.940	2.626	3.827	1.00	1.00	



## APPENDIX B

### SELECTION OF SITE CONTAMINANTS - COMPARISON OF SOLAR POND SOIL DATA WITH BACKGROUND SOIL DATA

Summaries of data that were used in screening inorganics and radionuclides as site contaminants based on a comparison with background are presented in Tables B-1 through B-12. The data are summarized according to soil type: alluvium (Tables B-1 through B-3), colluvium (Tables B-4 through B-6), sandstone (Tables B-7 through B-9), and claystone (Tables B-10 through B-12).

Table B-13 contains a list of the inorganics and radionuclides which were eliminated as site contaminants and indicates the reasons for their elimination. Those substances which were considered to be above background in one or more soil types are presented in Table B-14. There were some substances that were judged to be borderline, based on the available data (i.e., the sampling data did not clearly indicate if the chemical is present above or below background). The borderline chemicals were conservatively assumed to be above background.

Table B-1  
SOLAR EVAPORATION POND SOILS  
TOTAL METAL CONSTITUENT CONCENTRATIONS  
ABOVE BACKGROUND IN ROCKY FLATS ALLUVIUM  
ALL CONCENTRATIONS IN mg/kg

Analyte	Background Value	Number of Results	Number of Results Above Background	Reported when the maximum value exceeds Background	
				Maximum Value	Average of Values Above Background
Aluminum (Al)	25312.00	81	4	32700	31066
Antimony (Sb)	12.10U	81	1	12.615	12.6159
Arsenic (As)	15.86	81	3	35	27.7500
Barium (Ba)	155.80	81	14	269	197
Beryllium (Be)	11.27	81	0		
Cadmium (Cd)	3.20*	81	22	119.13	16.8406
Calcium (Ca)	43079.00	81	25	161428	90009
Cesium (Cs)	202.00U	42	0		
Chromium (Cr)	37.90	81	6	780.50	383
Cobalt (Co)	18.20*	81	3	29.478	21.9541
Copper (Cu)	20.03	81	12	58.480	27.1352
Iron (Fe)	22916.00	81	7	33500	27901
Lead (Pb)	18.04	81	12	27	20.9786
Lithium (Li)	44.40	80	2	776	438
Magnesium (Mg)	4425.00	81	4	7170	5627
Manganese (Mn)	422.90	81	6	802.12	544
Mercury (Hg)	0.58*	81	1	10.8	10.8000
Molybdenum (Mo)	38.65	79	0		
Nickel (Ni)	43.27	81	7	542.96	327
Potassium (K)	3336.00	81	11	5200	4069
Selenium (Se)	0.77U	81	3	1.3	1.2750
Silver (Ag)	40.90*	81	0		
Sodium (Na)	1010.00U	81	9	3578.0	2097
Strontium (Sr)	226.00*	81	6	354	264
Thallium (Tl)	1.50U	81	3	5.4458	5.3059
Tin (Sn)	338.00*	41	0		
Vanadium (V)	54.67	81	4	83.9	69.6667
Zinc (Zn)	52.64	81	8	103.12	67.6980

U-Detection Limit.

Notes: Maximum, and Average based on all available data. (Data rejected during validation is excluded.)  
Background values based on 1989 Round One Background Tolerance Intervals (\*where no tolerance interval, highest background value).

Table B-2  
SOLAR EVAPORATION POND SOILS  
INORGANIC CONSTITUENT CONCENTRATIONS  
ABOVE BACKGROUND IN ROCKY FLATS ALLUVIUM  
ALL CONCENTRATIONS IN MG/KG

Analyte	Background Value	Number of Results	Number of Results Above Background	Maximum Value	Reported when the maximum value exceeds Background	
					Average of Values Above Background	
Nitrate-Nitrite as N	4.30*	79	49	3400		260
pH	9.64	80	0			
Sulfide	13.00*	80	0			

U-Detection Limit.

Notes: Maximum, and Average based on all available data (data rejected during validation is excluded).  
Background values based on 1989 Tolerance Intervals (\*where no tolerance interval, highest background value).

Table B-3  
SOLAR EVAPORATION POND SOILS  
TOTAL RADIOCHEMISTRY CONCENTRATIONS  
ABOVE BACKGROUND IN ROCKY FLATS ALLUVIUM  
ALL CONCENTRATIONS IN pci/gm (pci/ml for tritium)

Analyte	Background Value	Number of Results	Number of Results Above Background	Maximum Value	Reported when the maximum value exceeds Background	
					Average of Values Above Background	Average of Values Above Background
Gross Alpha	37.11	51	4	110	69	
Gross Beta	36.89	51	0			
Uranium 233, 234	1.49	51	6	4.0	1.8	
Uranium 235	0.09	13	4	0.1	0.10	
Uranium 238	1.35	51	4	2.8	1.8	
Strontium 89, 90	0.77	51	0			
Plutonium 239, 240	0.02	51	14	18	2.2	
Americium 241	0.02	38	11	2.2	0.72	
Cesium 137	0.08	14	0			
Tritium	0.41	52	12	16	3.8	
Radium 226	1.33	13	0			
Radium 228	2.87	13	0			

\*MDA - Minimum Detectable Activity

Notes: Minimum, Maximum, and Average based on all available data.

Background values based on 1989 Tolerance Intervals. (Where no tolerance interval, highest background value is used.)

Table B-4  
SOLAR EVAPORATION POND SOILS  
TOTAL METAL CONSTITUENT CONCENTRATIONS  
ABOVE BACKGROUND IN COLLUVIUM  
ALL CONCENTRATIONS IN mg/kg

Analyte	Background Value	Number of Results	Number of Results Above Background	Reported when the maximum value exceeds Background	
				Maximum Value	Average of Values Above Background
Aluminum (Al)	21663.00	18	0		
Antimony (Sb)	13.000	18	0		
Arsenic (As)	7.70	18	1	8.0	8.0000
Barium (Ba)	345.80	18	0		
Beryllium (Be)	17.75	18	0		
Cadmium (Cd)	1.80*	18	16	4.0355	2.8439
Calcium (Ca)	20811.00	18	2	39907.	39566
Cesium (Cs)	274.00*	0	0		
Chromium (Cr)	26.80	18	2	39.784	37.6905
Cobalt (Co)	15.90*	18	1	15.952	15.9527
Copper (Cu)	26.70	18	0		
Iron (Fe)	29991.00	18	0		
Lead (Pb)	26.40	18	2	28	27.5000
Lithium (Li)	32.10	18	0		
Magnesium (Mg)	6151.00	18	0		
Manganese (Mn)	545.10	18	0		
Mercury (Hg)	0.44*	18	0		
Molybdenum (Mo)	32.78	18	0		
Nickel (Ni)	35.40	18	0		
Potassium (K)	2789.00	18	0		
Selenium (Se)	1.100	18	3	4000	3533
Silver (Ag)	33.50*	18	0		
Sodium (Na)	3680.00*	18	0		
Strontium (Sr)	111.10	18	0		
Thallium (Tl)	2.100	18	0		
Tin (Sn)	441.00*	0	0		
Vanadium (V)	58.20	18	0		
Zinc (Zn)	98.10	18	0		

U-Detection Limit.

Notes: Maximum, and Average based on all available data. (Data rejected during validation is excluded.)

Background values based on 1989 Round One Background Tolerance Intervals (\*where no tolerance interval, highest background value).

Table B-5  
SOLAR EVAPORATION POND SOILS  
INORGANIC CONSTITUENT CONCENTRATIONS  
ABOVE BACKGROUND IN COLLUVIUM  
ALL CONCENTRATIONS IN MG/KG

Analyte	Background Value	Number of Results	Number of Results		Maximum Value		Average of Values Above Background	
			Above Background		Value		Above Background	
Nitrate-Nitrite as N	4.27	18	8		511		190	
pH	9.48	18	0					
Sulfide	5.00*	18	0					

U-Detection Limit.

Notes: Maximum, and Average based on all available data (data rejected during validation is excluded).  
Background values based on 1989 Tolerance Intervals (\*where no tolerance interval, highest background value).



Table B-6  
SOLAR EVAPORATION POND SOILS  
TOTAL RADIOCHEMISTRY CONCENTRATIONS  
ABOVE BACKGROUND IN COLLUVIUM  
ALL CONCENTRATIONS IN pci/gm (pci/ml for tritium)

Reported when the maximum value exceeds Background

Analyte	Background Value	Number of Results	Number of Results Above Background		Maximum Value		Average of Values Above Background	
			Results	Above Background	Value	Above Background	Value	Above Background
Gross Alpha	51.71	18		0				
Gross Beta	35.13	18		0				
Uranium 233, 234	1.76	18		1	3.7	3.7	3.7	3.7
Uranium 235	0.17	0		0				
Uranium 238	1.68	18		1	1.7	1.7	1.7	1.7
Strontium 89, 90	0.78	18		0				
Plutonium 239, 240	0.02	18		2	3.5	3.5	1.9	1.9
Americium 241	0.001	18		1	0.59	0.59	0.59	0.59
Cesium 137	0.11	0		0				
Tritium	0.30	18		2	3.0	3.0	1.9	1.9
Radium 226	2.59	0		0				
Radium 228	3.82	0		0				

\*MDA - Minimum Detectable Activity

Notes: Minimum, Maximum, and Average based on all available data.  
Background values based on 1989 Tolerance Intervals. (Where no tolerance interval, highest background value is used.)

Table B-7

**SOLAR EVAPORATION POND SOILS  
TOTAL METAL CONSTITUENT CONCENTRATIONS  
ABOVE BACKGROUND IN SANDSTONE  
ALL CONCENTRATIONS IN mg/kg**

Reported when the maximum value exceeds Background

Analyte	Background Value	Number of Results	Number of Results Above Background	Maximum Value	Average of Values Above Background
Aluminum (Al)	10300.00*	28	1	11220.	11221
Antimony (Sb)	12.80U	28	0		
Arsenic (As)	3.60*	28	14	24.6	6.8318
Barium (Ba)	165.00*	28	1	169	169
Beryllium (Be)	2.20*	28	7	7.2	3.6902
Cadmium (Cd)	1.10U	28	18	3.5114	2.4025
Calcium (Ca)	5940.00*	28	6	50604.	19208
Cesium (Cs)	213.00U	28	10		
Chromium (Cr)	10.70*	28	6	611.99	134
Cobalt (Co)	20.50*	28	0		
Copper (Cu)	19.60*	28	4	31.830	27.7540
Iron (Fe)	12300.00*	28	6	28400	20322
Lead (Pb)	13.40*	28	16	26	18.5000
Lithium (Li)	7.00*	26	0		
Magnesium (Mg)	2520.00*	28	2	3329.5	2935
Manganese (Mn)	305.00*	28	3	407.80	372
Mercury (Hg)	0.27*	28	0		
Molybdenum (Mo)	11.20*	28	0		
Nickel (Ni)	14.30*	28	8		
Potassium (K)	1070.00U	27	11	366.35	56.1830
Selenium (Se)	1.10U	28	0	3500	1602
Silver (Ag)	12.70*	28	0		
Sodium (Na)	1070.00U	28	2	1827.0	1583
Strontium (Sr)	69.20*	28	3	189	126
Thallium (Tl)	2.20U	28	0		
Tin (Sn)	268.00*	10	0		
Vanadium (V)	22.20*	28	9	60.5	43.1294
Zinc (Zn)	79.90*	28	2	90.9	87.5896

U-Detection Limit.

Notes: Maximum, and Average based on all available data. (Data rejected during validation is excluded.)

Background values based on 1989 Round One Background Tolerance Intervals (\*where no tolerance interval, highest background value).

B-8

Table B-8

SOLAR EVAPORATION POND SOILS  
INORGANIC CONSTITUENT CONCENTRATIONS  
ABOVE BACKGROUND IN SANDSTONE  
ALL CONCENTRATIONS IN MG/KG

Reported when the maximum value exceeds Background

Analyte	Background Value	Number of Results	Number of Results Above Background	Maximum Value	Average of Values Above Background
Nitrate-Nitrite as N	1.90*	25	15	638	61
pH	9.20*	25	0		
Sulfide	2.00*	25	0		

U-Detection Limit.

Notes: Maximum, and Average based on all available data (data rejected during validation is excluded).

Background values based on 1989 Tolerance Intervals (\*where no tolerance interval, highest background value).

Table B-9

**SOLAR EVAPORATION POND SOILS  
TOTAL RADIOCHEMISTRY CONCENTRATIONS  
ABOVE BACKGROUND IN SANDSTONE  
ALL CONCENTRATIONS IN pci/gm (pci/ml for tritium)**

Reported when the maximum value exceeds Background

Analyte	Background Value	Number of Results	Number of Results Above Background	Maximum Value	Average of Values Above Background
Gross Alpha	37.00*	18	1	39	39
Gross Beta	29.00*	18	4	33	32
Uranium 233, 234	0.80*	18	10	1.7	1.2
Uranium 235	0.10*	0	0		
Uranium 238	1.00*	18	5	1.6	1.3
Strontium 89, 90	0.40*	18	0		
Plutonium 239, 240	0.01*	18	0		
Americium 241	0.001	18	1	0.08	0.080
Cesium 137	0.00*	0	0		
Tritium	0.39*	18	2	3.8	3.3
Radium 226	1.00*	0	0		
Radium 228	1.10*	0	0		

\*MDA-Minimum Detectable Activity

Notes: Minimum, Maximum, and Average based on all available data.

Background values based on 1989 Tolerance Intervals. (Where no tolerance interval, highest background value is used.)

Table B-10

**SOLAR EVAPORATION POND SOILS**  
**TOTAL METAL CONSTITUENT CONCENTRATIONS**  
**ABOVE BACKGROUND IN CLAYSTONE**  
**ALL CONCENTRATIONS IN mg/kg**

Analyte	Background Value	Number of Results	Number of Results Above Background	Reported when the maximum value exceeds Background	
				Maximum Value	Average of Values Above Background
Aluminum (Al)	13495.00	44	4	15699.	14891
Antimony (Sb)	16.20*	44	0		
Arsenic (As)	15.05	44	9	64	27.3750
Barium (Ba)	240.10	44	3	919.30	508
Beryllium (Be)	11.80	44	0		
Cadmium (Cd)	1.100	44	41	100.66	3.5565
Calcium (Ca)	10183.00	44	11	85844.	25955
Cesium (Cs)	212.000	3	0		
Chromium (Cr)	16.57	44	8	91.919	29.7168
Cobalt (Co)	29.70*	44	0		
Copper (Cu)	30.62	44	0		
Iron (Fe)	41295.00	44	0		
Lead (Pb)	34.50	44	2	86.9	61.9500
Lithium (Li)	33.37	44	0		
Magnesium (Mg)	4896.00	44	1	5217.1	5217
Manganese (Mn)	656.00	44	1	1257.9	1258
Mercury (Hg)	0.35*	44	0		
Molybdenum (Mo)	33.68	43	0		
Nickel (Ni)	56.95	44	1		
Potassium (K)	1400.00*	44	8	94.475	94.4750
Selenium (Se)	1.100	44	1	2200	1680
Silver (Ag)	18.70*	44	0	1.2	1.2000
Sodium (Na)	1060.000	44	3	1611.2	1443
Strontium (Sr)	144.42	44	1	162.10	162
Thallium (Tl)	2.100	44	5	5.7409	5.3507
Tin (Sn)	274.00*	3	0		
Vanadium (V)	47.70	44	2	49.700	49.4595
Zinc (Zn)	106.70	44	3	125.92	119

U-Detection Limit.

Notes: Maximum, and Average based on all available data. (Data rejected during validation is excluded.)

Background values based on 1989 Round One Background Tolerance Intervals (\*where no tolerance interval, highest background value).

Table B-11

**SOLAR EVAPORATION POND SOILS  
INORGANIC CONSTITUENT CONCENTRATIONS  
ABOVE BACKGROUND IN CLAYSTONE  
ALL CONCENTRATIONS IN MG/KG**

Analyte	Background Value	Number of Results	Number of Results Above Background	Reported when the maximum value exceeds Background	
				Maximum Value	Average of Values Above Background
Nitrate-Nitrite as N	2.00*	45	34	656	86
pH	10.14	45	0		
Sulfide	5.00*	45	0		

U-Detection Limit.

Notes: Maximum, and Average based on all available data (data rejected during validation is excluded).  
Background values based on 1989 Tolerance Intervals (\*where no tolerance interval, highest background value).

Table B-12  
SOLAR EVAPORATION POND SOILS  
TOTAL RADIOCHEMISTRY CONCENTRATIONS  
ABOVE BACKGROUND IN CLAYSTONE  
ALL CONCENTRATIONS IN pci/gm (pci/ml for tritium)

Reported when the maximum value exceeds Background

Analyte	Background Value	Number of Results	Number of Results Above Background	Maximum Value	Average of Values Above Background
Gross Alpha	46.00*	43	0		
Gross Beta	32.00*	43	0		
Uranium 233, 234	1.70*	43	1	1.8	1.8
Uranium 235	0.30*	1	0		
Uranium 238	1.40*	43	6	1.7	1.6
Strontium 89, 90	0.70*	43	2	1.1	0.95
Plutonium 239, 240	0.01*	43	1	0.13	0.13
Americium 241	0.001	42	6	0.16	0.099
Cesium 137	0.00*	1	0		
Tritium	0.28*	43	9	2.3	1.3
Radium 226	1.30*	1	0		
Radium 228	1.60*	1	0		

\*MDA-Minimum Detectable Activity

Notes: Minimum, Maximum, and Average based on all available data.

Background values based on 1989 Tolerance Intervals. (Where no tolerance interval, highest background value is used.)

Table B-13

**Inorganics and Radionuclides Eliminated as Site  
Contaminants Based on a Comparison with  
Background**

Analyte	Reason(s) for Elimination
<u>Inorganics</u>	
Aluminum	<ul style="list-style-type: none"> <li>- less than 10 percent of the samples for any soil type were above background</li> <li>- average of values above background were close to background value</li> </ul>
Antimony	<ul style="list-style-type: none"> <li>- only one sample in one soil type was above background</li> </ul>
Cesium	<ul style="list-style-type: none"> <li>- not detected above background in any soil type</li> </ul>
Cobalt	<ul style="list-style-type: none"> <li>- less than six percent of the samples for any soil type were above background</li> <li>- average of values above background were close to background value</li> </ul>
Copper	<ul style="list-style-type: none"> <li>- above background in only one soil type</li> <li>- average of values above background were close to background value</li> </ul>
Magnesium	<ul style="list-style-type: none"> <li>- less than seven percent of the samples for any soil type were above background</li> <li>- average of values above background were close to background value</li> </ul>



Table B-13  
(continued)

Analyte	Reason(s) for Elimination
<u>Inorganics</u>	
Manganese	<ul style="list-style-type: none"> <li>- less than eight percent of the samples for the alluvium, none of the colluvium samples, and 0.3 percent of the claystone samples were above background</li> <li>- average of values above background in alluvium, colluvium, and sandstone were close to background value</li> </ul>
Molybdenum	<ul style="list-style-type: none"> <li>- not detected above background in any soil type</li> </ul>
Silver	<ul style="list-style-type: none"> <li>- not detected above background in any soil type</li> </ul>
Tin	<ul style="list-style-type: none"> <li>- not detected above background in any soil type</li> </ul>
Zinc	<ul style="list-style-type: none"> <li>- less than 10 percent of the samples for any soil type were above background</li> <li>- average of values above background were close to background value</li> </ul>
<u>Radionuclides</u>	
Cesium	<ul style="list-style-type: none"> <li>- not detected above background in any soil type</li> </ul>
Radium 226	<ul style="list-style-type: none"> <li>- not detected above background in any soil type</li> </ul>
Radium 228	<ul style="list-style-type: none"> <li>- not detected above background in any soil type</li> </ul>
Uranium 235	<ul style="list-style-type: none"> <li>- average of values above background very close to background value</li> </ul>

Table B-14

**Inorganics and Radionuclides Considered  
to be Above Background<sup>1</sup>**

Inorganics	Radionuclides
Arsenic	Americium 241
Barium (B)	Plutonium 239, 240
Beryllium (B)	Strontium 89, 90 (B)
Cadmium	Tritium
Calcium	Uranium 233, 234
Chromium	Uranium 238
Iron (B)	
Lead (B)	
Lithium	
Mercury (B)	
Nickel	
Nitrate	
Potassium (B)	
Selenium (B)	
Sodium (B)	
Strontium (B)	
Thallium (B)	
Vanadium	

<sup>1</sup> Substance is considered to be above background in one or more soil types.

(B) = Borderline. The sampling data do not clearly indicate if the chemical is present above or below background.



## APPENDIX C

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### MEMORANDUM TO ROCKWELL INTERNATIONAL CONCERNING APPROACH TO DERIVING TOXICITY VALUES (HEALTH CRITERIA)

# MEMORANDUM

August 11, 1989

TO: Laura Frick

FROM: Charles Dobroski  
Robert Warwick

RE: Task #7: Health Criteria for Rocky Flats Solar  
Pond TCL Project

Please find attached:

- o A table summarizing available health criteria endpoints for the contaminants of concern. The criteria are taken from the Health Effects Assessment Summary Tables, 2nd Quarter, FY 1989, U.S. EPA, OSWER (OS-230), ORD (RD-689), OERR 9200.6-303-(89-2), April, 1989. This table also notes those chemicals for which there are no criteria currently available in the HEA Summary Table.
- o A table of health criteria endpoints for the radionuclides that was prepared by Don Dunning.

The approaches that will be employed to derive health-based criteria endpoints for the chemicals for which they are not currently available are outlined below:.

## Cancer Potency Factors

- o If no current potency factor is available for a specific exposure route, older factors developed for the same route will be re-evaluated.
- o If a potency factor is available for only one exposure route, oral or inhalation, the potency factor will be used for both exposure routes if the toxic effects through both routes are the same.
- o Because there are no dermal potency factors, the more conservative of the oral or inhalation factors will be used for the dermal route.

## Reference Doses (RfD)

### o Inhalation

- o The threshold limit value (TLV-TWA; , ACGIH) for the chemical will be used as the basis for the RfD. If there is also an older inhalation RfD, it will be re-evaluated and the more conservative factor will be used.
- o If there is only an older factor, it will be re-evaluated.
- o If no TLV or older factor is available:
  - o Organic chemicals. The oral RfD will be used, since it is likely these compounds will be systemically absorbed following inhalation.
  - o Inorganic Chemicals. The oral RfD will be used only if the toxic effects by both the oral and the inhalation exposure routes are the same.

### o Oral

- o Both Organic and Inorganic Chemicals.
  - o An RfD on which the lifetime health advisory for drinking water (U.S. EPA) is based will be used if available.
  - o Old oral RfDs will be re-evaluated if the health advisory is not available.
  - o Other health-based water quality criteria (e.g., adjusted acceptable daily intake) will be used to derive an RfD.
  - o An inhalation RfD will be used, if systemic effects are the basis for the criterion.

### o Dermal

- o Because there are no dermal RfDs, the more conservative of the oral or inhalation factors will be used.

Note: If no criteria are available from which to derive RfDs, the original literature will be searched for suitable data on which to base an RfD. The RfD will be derived according to U.S. EPA guidelines.

Table 1. Available Toxicological Endpoints for Nonradioactive Chemicals

CHEMICAL	Carcinogenic Criteria		Non-Carcinogenic Criteria	
	CAG Group/Potency Factor (q*)		Reference Dose (RfD)	
	Inhalation (ug/m <sup>3</sup> )-1 [(mg/kg/day)-1]	Oral [(mg/kg/day)-1]	Inhalation mg/m <sup>3</sup> [mg/kg/day]	Oral [mg/kg/day]
Acetone	NA	NA	<del>5.0E-06 (a)</del>	1.0E-01 (b)
Aluminum	NA	NA	NA	ND
Americium	NA	NA	NA	NA
Antimony	NA	NA	ND	4.0E-04 (b)
Arsenic	A/4.3E-03 (b) [5.0E+01] (b)	A/ND	ND	ND
Barium	D/NA	D/NA	5.0E-04 (b) (1.0E-04)	5.0E-02 (b)
Beryllium	B2/2.4E-03 (b) [8.4E+00] (b)	B2/4.86E+00 (c)	ND	5.0E-03 (b)
Bis(2-ethylhexyl- phthalate	B2/ND	B2/1.4E-02 (b)	ND	2.0E-02 (a)
2-Butanone	NA	NA	<del>2.2E-01</del> 3.0E-01 [9.0E-02]	5.0E-02
Cadmium	B1/1.8E-03 (b) [6.1E+00] (a)	NA	ND	1.0E-03 (food) 5.0E-04 (water)
Calcium	NA	NA	NA	NA
Carbon Tetrachloride	B2/1.5E-05 (a,b,d) [1.3E-01] (a,b); 5.2E-02 (d)	B2/1.3E+00 (a)	ND	7.0E-04 (a)
Chloride	NA	NA	NA	NA
Chloroform	B2/2.3E-05	B2/6.1E-03 (a)	ND	1.0E-02 (a)
Chromium (Hexavalent)	A1/1.2E-02 (b) [4.1E+01] (a)	ND	ND	5.0E-03

Table 1. Available Toxicological Endpoints for Nonradioactive Chemicals

Cobalt	NA	NA	NA	NA
Copper	NA	NA	ND	1.3 mg/l
Cyanide	NA	NA	ND	2.0E-02 (a)
1,1-Dichloroethane	NA	B2/9.1E-02	5.0E-01 [1.0E-01]	1.0E-01 (b)
1,2-Dichloroethane	B2/2.6E-05 [9.1E-02] (a,b)	B2/9.1E-02 (a)	ND	ND
1,1-Dichloroethene	C/5.0E-05 [1.2E+00] (a)	C/6.0E-01 (a)	ND	9.0E-03 (a)
BCO3	NA	NA	NA	NA
Iron	ND	ND	ND	ND
Lead	B2/ND (a)	B2/ND (a)	ND	ND
Lithium	NA	NA	NA	NA
Magnesium	NA	NA	NA	NA
Manganese	NA	NA	1.0E-03 [3.0E-04]	2.0E-01
Mercury	D/	D/	ND	3.4E-04 (methylmercury)
Methylene Chloride	B2/4.1E-06 [1.4E-02] (a)	B2/7.5E-03 (a)	3 (NA)	6.0E-02
Molybdenum	NA	NA	ND	ND
Nickel	A/2.4E-04 [1.4E-02] (a) 8E-01	NA	ND	2.0E-02 (a)
Nitrate	D/	D/	NA	NA
Phosphorus	NA	NA	NA	NA
Potassium	NA	NA	NA	NA

Table 1. Available Toxicological Endpoints for Nonradioactive Chemicals

Selenium	::	NA	NA	::	4.0E-03 [1.0E-03]	3.0E-03 (g)	::
Silver	::	NA	NA	::	NA	3.0E-03	::
Sodium	::	NA	NA	::	NA	NA	::
Sulfate	::	NA	NA	::	NA	NA	::
Tetrachloroethene	::	B2/9.5E-07 [3.3E-03]	<del>B2/9.5E-07</del> 5.1E-02	::	ND	1.0E-02 (a)	::
Thallium (insoluble salts)	::	NA	NA	::	ND	7.0E-05	::
1,1,1-Trichloroethane	::	NA	NA	::	1.0E+00 [1.0E-03] 3.0E-01	9.0E-02 (a,b)	::
1,1,2-Trichloroethane	::	C/1.6E-05 [5.7E-02] (a,b)	C/5.7E-02 (a)	::	ND	4.0E-03 (a)	::
Trichloroethene	::	B2/1.3E-06 (a,b,e) [5.7E-02] (a,b)	B2/1.1E-02 (a)	::	ND	ND	::
Vanadium	::	NA	NA	::	ND	7.0E-03	::
Vinyl Chloride	::	A/4.2E-05 (a,b,e) [2.95E-01] (f)	A/2.3E+00	::	ND	ND	::
Zinc	::	NA	NA	::	ND	2.0E-01	::



### Footnotes

[Table 1: Available Toxicological Endpoints for Nonradioactive Chemicals; Rocky Flats Solar Pond TCL Project]

- (a) Verified on IRIS (Integrated Risk Information System, U.S. EPA)
  - (b) Based upon route to route extrapolation
  - (c) There is inadequate evidence for carcinogenicity of this compound by the oral route.
  - (d) Incorporates an absorption factor of 0.4.  $1.3E-01$  (mg/kg/day)<sup>-1</sup> as administered and  $5.2E-02$  (mg/kg/day)<sup>-1</sup> as absorbed dose
  - (e) A new unit risk of  $1.7E-06$  (ug/m<sup>3</sup>)<sup>-1</sup> has been proposed in the Addendum to the HAD (U.S. EPA, 1987) and adopted in the update HEA (U.S. EPA, 1988)
  - (f) Based on metabolized dose
- NA Not applicable
- ND Not determined

## APPENDIX D

ADDITIONAL APPROACHES TO CALCULATING REFERENCE DOSES  
FOR SELECTED SITE CONTAMINANTS

Oral and /or inhalation reference doses (RfDs) were not available for some site contaminants. In Subsection 4.2 an approach to calculating inhalation RfDs from a threshold limit value-time weighted average (TLV-TWA) was described. In this appendix, additional approaches that were used to derive RfDs for site contaminants are presented.

Oral reference doses (RfDs) were derived for nine of the site contaminants. Several of the RfDs were derived from drinking water or other available toxicity-based values. The remainder were derived from toxicity data, using guidelines developed by the U.S. EPA (EPA, 1989d). These guidelines involve the application of uncertainty factors and a modifying factor to a NOAEL (no-observed-adverse-effect level) or a LOAEL (lowest-observed-adverse-effect level) selected from the scientific literature. Standard uncertainty factors of 10 each are applied for the following: to account for variation in the general population (i.e., to protect sensitive populations), when extrapolating from animal data, when using data from a subchronic study, and when using a LOAEL. A modifying factor ranging from greater than zero to ten is included as a reflection of a professional judgment of additional uncertainty in the database.

An inhalation RfD was also derived for one of the nine contaminants (i.e., lithium) based on toxicity information, using the TLV-TWA approach described in Subsection 4.2.

## D.1 Inorganics

### Iron

An oral RfD for iron was calculated based on information indicating that toxic effects due to iron ingestion (i.e., mild gastrointestinal irritation) may be evidenced in humans at doses of 30 to 50 mg/kg (Goldfrank et al., 1986). Assuming that 30 mg/kg represents the LOAEL, incorporating an uncertainty factor of 10 for extrapolating from a LOAEL to a NOAEL and applying a modifying factor of 1, an RfD of  $3.0E+00$  mg/kg/day was derived.

### Lead

In 1985, EPA proposed a maximum contaminant level goal (MCLG) for lead of 20 ug/l. An MCLG is a nonenforceable health goal for public drinking water supplies. The proposed MCLG was based on blood levels in infants of 15 to 20 ug/dl representing levels of concern and assumed 100 percent exposure was from drinking water. However, EPA has more recently proposed an MCLG of zero and an MCL of 5-10 ug/l (EPA, 1988). An MCL is an enforceable standard for public drinking water supplies. The most conservative proposed MCL (i.e., 5 ug/l) was used to derive the oral RfD for lead. Assuming the consumption of two liters of water/day and a body weight of 70 kg (EPA, 1989d), an oral RfD of  $1.4E-04$  mg/kg/day was calculated for lead.

### Lithium

Lithium (as lithium carbonate) is used for maintenance therapy of acute mania at doses of approximately 1200-1800 mg/day (equivalent to approximately 169 to 226 mg/day of lithium ion (Jefferson et al., 1983). An oral RfD was calculated for lithium based on the lowest maintenance dose (i.e., 169 mg/day),

assuming a body weight of 70 kg (EPA, 1989d). Because adverse dermatological reactions (i.e., rashes) have been associated with therapeutic dosages in some individuals (Clayton and Clayton, 1981), an uncertainty factor of 10 was applied to arrive at a NOAEL. An additional uncertainty factor of 10 was used to account for human variation. Based on these assumptions, an oral RfD of  $2.4\text{E-}02$  mg/kg/day was derived for lithium.

Lithium hydride was the only form of lithium for which inhalation toxicity data were available. Lithium hydride is intensely irritating and corrosive to the skin and mucus membranes and its TLV-TWA of  $0.025$  mg/m<sup>3</sup> (ACGIH, 1989) is based on its irritant properties. However, concentrations ranging from  $0.025$  to  $0.10$  mg/m<sup>3</sup>, which have been associated with a tickling sensation in the nose and a mild nasal discharge, have been reported to be tolerated by workers who are continuously exposed (Clayton and Clayton, 1981).

Lithium was previously disposed of in the solar ponds as lithium chloride and lithium metal (DOE, 1987). Lithium would not be expected to be present as the hydride on site and there has been no evidence of industrial health hazards being associated with the inhalation of other forms of lithium (Clayton and Clayton, 1981). Therefore, the use of the TLV-TWA for lithium hydride to derive an inhalation RfD on which to base a clean-up level for lithium will be expected to be overly conservative. In the absence of inhalation data for other forms for lithium, however, the upper limit of the tolerated range for lithium hydride (i.e.,  $0.10$  mg/m<sup>3</sup>) was assumed to be an acceptable exposure level for workers for other forms of lithium. Substituting this value as the "TLV-TWA" in the equation presented in Section 4.0, Table 4-4, an inhalation RfD of  $1.0\text{E-}04$  mg/kg/day was derived for lithium for the general public.

## Sulfate

The current maximum contaminant level (MCL) for sulfate was used to develop an oral RfD. The MCL of 250 mg/l for sulfate is based on its laxative effects (EPA, 1977). Assuming the consumption of 2 liters of water per day, and a body weight of 70 kg (EPA, 1989d), an oral RfD of  $7.1E+00$  mg/kg/day was derived for sulfate.

## Strontium

An oral RfD for strontium was developed based on a 90-day feeding study in rats in which 300 ppm of strontium hexahydrate in the diet was tentatively (see below) identified as a NOAEL (Kroes et al., 1977). The dietary concentration was converted to a daily intake of strontium of 7.88 mg/kg/day, by assuming that a rat consumes 20 grams of food/day and weighs 250 grams, and by taking into account the percentage of strontium in strontium hexahydrate (i.e., 32.86 percent). The body weight and food intake were those used by the National Research Council in deriving a 7-day drinking water standard for strontium based on the Kroes et al. study (NRC, 1982). Uncertainty factors of 10 each were applied for using data from a subchronic study, for extrapolating from animal data, and for human variation. Because the investigators questioned whether the accumulation of strontium in the bone which was seen at 300 ppm represented an adverse effect, a modifying factor of 5 was also incorporated into the derivation of the oral RfD. Based on these considerations, an oral RfD of  $1.6E-03$  mg/kg/day was derived for strontium.

## Uranium

Kidney toxicity is the primary noncarcinogenic toxic effect of excessive exposure to uranium. The NOAEL for kidney toxicity,

based on long-term animal studies, is reported to range from 0.1 to 1.0 mg/kg/day (as uranyl nitrate) (EPA, 1985a). An oral RfD was derived for uranium from the lower limit of the NOAEL range (i.e., 0.1 mg/kg/day), adjusting for the percentage of uranium in uranyl nitrate (60.4 percent). Applying uncertainty factors of 10 each for extrapolating from animal data and for human variation, an oral RfD of  $6.0\text{E-}04$  mg/kg/day was derived.

## D.2 Organics

### 1,2 Dichloroethane

For 1,2-dichloroethane, an adjusted acceptable daily intake (AADI) of 0.260 mg/l was used as the basis for the oral reference dose. The AADI was derived from a NOAEL reported in an 8-month inhalation study on a variety of animals, in which changes in the liver, lungs, kidney, adrenals, and heart were the toxic endpoints (EPA, 1984b). Assuming the ingestion of 2 liters of water per day and a body weight of 70 kg (EPA, 1989d), an oral RfD of  $7.4\text{E-}03$  mg/kg/day was calculated.

### Naphthalene

The oral RfD for naphthalene ( $4.1\text{E-}03$  mg/kg/day) adjusted by a modifying factor of 100 to give an oral RfD of  $4.1\text{E-}05$  mg/kg/day, was used for the PAHs (total). Naphthalene is the only PAH for which an oral reference dose has been developed by EPA (EPA, 1989a). Because the structure of naphthalene differs substantially from many of the PAHs, its toxicity may also be substantially different. Therefore, a conservative modifying factor of 100 was used.

Vinyl Chloride

An oral RfD of  $1.3\text{E}-03$  mg/kg/day was developed for vinyl chloride based on a NOAEL of 0.13 mg/kg/day reported in a lifetime study in rats in which decreased survival and hepatotoxicity were the most sensitive toxic endpoints (ATSDR, 1988b). Uncertainty factors of 10 each were incorporated to account for extrapolation from animal data and for human variation. A modifying factor of 1 was used.

## APPENDIX E

### APPROACHES TO DERIVING MODELS FOR DETERMINING RISK-BASED SOIL CONCENTRATIONS FOR INDIVIDUAL EXPOSURE ROUTES

All of the equations used in the derivaton of models for determining soil clean-up levels are in accord with current U.S. EPA guidance for performing human health exposure and risk assessments (EPA, 1985b, 1987b, 1989d).

#### E.1 Models Based on Carcinogenic Risk

The algorithms for determining soil concentrations for carcinogenic site contaminants based on carcinogenic risk were derived for each exposure route (with the exceptions of the inhalation of airborne contaminated soil and the inhalation of vapors) from two equations, one for calculating lifetime carcinogenic risk, and the other for determining estimated daily intakes (EPA, 1989d). It was assumed in the derivation that individuals are continuously exposed to contaminants over a 70-year lifetime.

The general equation that is used to calculate carcinogenic risk is the same for each exposure route:

$$\begin{array}{rclcl}
 \text{(E-1)} & \text{Carcinogenic} & \text{Estimated} & & \text{Carcinogenic} \\
 & \text{Risk} & \text{Daily Intake} & \times & \text{Potency} \\
 & & \text{(mg/kg/day)} & & \text{Factor} \\
 & & & & \text{(mg/kg/day)}^{-1}
 \end{array}$$

The equation for determining estimated daily intake varies for each exposure route, depending on the applicable exposure factors. However, for all of the routes, the intakes (as ex-



pressed in mg (contaminant)/kg(body weight)/day) are directly proportional to the soil concentration and inversely proportional to body weight.

The general equation that is used to calculate estimated daily intake is as follows:

$$(E-2) \quad \begin{array}{l} \text{Estimated} \\ \text{Daily Intake} \\ \text{(mg/kg/day)} \end{array} = \begin{array}{l} \text{Contaminant} \\ \text{Concentration} \\ \text{in Soil} \\ \text{(mg/kg)} \end{array} \times \begin{array}{l} \text{Route-Specific} \\ \text{Exposure} \\ \text{Factors} \\ \text{(kg/day)}^1 \end{array}$$


---


$$\begin{array}{c} \text{Body Weight} \\ \text{(kg)} \end{array}$$

By substituting equation (E-2) in equation (E-1) and solving for "Contaminant Concentration in Soil," the following general equation was derived for determining soil concentrations based on carcinogenic risk:

$$(E-3) \quad \begin{array}{l} \text{Contaminant} \\ \text{Concentration} \\ \text{in soil} \\ \text{(mg/kg)} \end{array} = \frac{\begin{array}{l} \text{Carcinogenic Risk} \\ \text{Route-Specific} \\ \text{Exposure Factors} \\ \text{(kg/day)} \end{array} \times \begin{array}{l} \text{Body Weight} \\ \text{(kg)} \\ \text{Carcinogenic} \\ \text{Potency Factor} \\ \text{(mg/kg/day)}^{-1} \end{array}}{\begin{array}{l} \text{Carcinogenic} \\ \text{Potency Factor} \\ \text{(mg/kg/day)}^{-1} \end{array}}$$

The route-specific exposure factors (including unit conversion factors) that were used to derive the final equation for each applicable exposure route are presented in Table E-1. The final equations for soil concentrations based on carcinogenic risk are presented in the text in Tables 5-1, 5-3, and 5-5 for the incidental soil ingestion, vegetable ingestion, and dermal contact with soil exposure routes, respectively.

<sup>1</sup> Net unit based on all route-specific exposure factors combined

Table E-1

## Route-Specific Exposure Factors/Unit Conversion Factors

---

### Incidental Soil Ingestion

- Soil ingestion rate (mg/day).
- Number of weeks exposed per year (weeks/year).
- Conversion factors ( $10^{-6}$  kg/mg; 1 year/52 weeks).

### (Root) Vegetable Ingestion

- Root vegetable ingestion rate (g/day).
- Fraction of vegetables that are home-grown (unitless).
- Root uptake factor (unitless).
- Conversion factor ( $10^{-3}$  kg/g).

### Dermal Contact with Soil

- Exposed skin surface area ( $\text{cm}^2/\text{day}$ ).
  - Skin adherence factor (unitless).
  - Dermal absorption factor (unitless).
  - Number of weeks exposed per year (weeks/year).
  - Unit conversion factors ( $10^{-6}$  kg/mg; 1 year/52 weeks).
-

The approach to deriving the soil concentration equations for the inhalation of airborne contaminated soil and the inhalation of vapors exposure routes was also based on two equations, one for calculating lifetime carcinogenic risk (EPA, 1989d), the other for determining the concentration of a contaminant in air based on fugitive dust emissions (EPA, 1985b) or vapor emissions (EPA, 1987b).

$$(E-4) \quad \begin{array}{l} \text{Carcinogenic} \\ \text{Risk} \end{array} = \begin{array}{l} \text{Air Concentration} \\ \text{of Contaminant} \\ (\text{ug}/\text{m}^3) \end{array} \times \begin{array}{l} \text{Inhalation} \\ \text{Unit Risk} \\ \text{Factor} \\ (\text{ug}/\text{m}^3)^{-1} \end{array}$$

$$(E-5) \quad \begin{array}{l} \text{Air Concentration} \\ \text{of Contaminant} \\ (\text{ug}/\text{m}^3) \end{array} = \begin{array}{l} \text{Contaminant} \\ \text{Concentration} \\ \text{in Soil} \\ (\text{mg}/\text{kg}) \end{array} \times \begin{array}{l} \text{Dust} \\ \text{Generation/Vapor} \\ \text{Generation} \\ \text{Factors} \\ (\text{ug}/\text{m}^3 \times \text{kg}/\text{mg})^1 \end{array}$$

The dust generation factors are based on the Industrial Source Complex Long Term (ISCLT) model developed by the U.S. EPA (EPA, 1985b). The vapor generation factors are based on a land treatment emission model (EPA, 1987b). The factors that were included in the ISCLT and land treatment emission models are presented in Tables E-2 and E-3, respectively.

By substituting equation (E-5) in equation (E-4) and solving for "Contaminant Concentration in Soil," the following equation was derived for determining soil concentrations based on carcinogenic risk through the inhalation of contaminated soil and inhalation of vapors exposure routes:

---

<sup>1</sup> Net units based on all dust generation/vapor emission factors and unit risk factors combined.

Table E-2

**Dust Generation Factors Used in the Soil Concentration Models  
for the Inhalation of Contaminated Soil Exposure Route**

---

$F_1$	=	Unscaled concentration due to a unit erosion rate ( $\mu\text{g}/\text{m}^3$ )/(g/sec)
PM <sub>10</sub> Emission Factor	=	Annual average PM <sub>10</sub> emission rate per unit of contaminated surface ( $\text{mg}/\text{m}^2/\text{hr}$ )
Surface Area	=	Area of contaminated soil ( $\text{m}^2$ )
Climatic Region Factor	=	Region-specific factor (1/unitless factor)
Unit Conversion Factors		
- Model based on carcinogenic risk	=	$10^{-3}$ g/mg; $10^{-6}$ kg/mg; 1 hr/3,600 sec
- Model based on noncarcin- ogenic risk	=	$10^{-3}$ g/mg; $10^{-6}$ kg/mg; $10^{-3}$ mg/ $\mu\text{g}$ ; 1 hr/3,600 sec

---

Table E-3

Vapor Generation Factors Used in the Soil  
Concentration Models for the Inhalation of Vapors  
Exposure Route

---

$P_{\text{soil}}$	=	Density of the soil ( $\text{g}/\text{cm}^3$ )
Surface Area	=	Area of contaminated soil ( $\text{m}^2$ )
$F_a$	=	Fraction of the contaminant released to the air during 70 years (unitless)
$L$	=	Depth of contaminated soil (cm)
$X/Q$	=	Contaminant concentration in air/emissions rate ( $\text{ug}/\text{m}^3/(\text{g}/\text{sec})$ )
$T$	=	Time after waste is applied to the soil ( $\text{sec}^{-1}$ )
Unit Conversion Factors		
- Model based on carcinogenic risk	=	$10^4 \text{ cm}^2/\text{m}^2$ ; $10^{-6} (\text{g}/\text{g})/(\text{mg}/\text{kg})$
- Model based on noncarcinogenic risk	=	$10^4 \text{ cm}^2/\text{m}^2$ ; $10^{-6} (\text{g}/\text{g})/(\text{mg}/\text{kg})$ ; $10^{-3} \text{ mg}/\text{ug}$

---

(E-6) Contaminant Concentration in Soil (mg/kg)	=	<div style="text-align: center;">Carcinogenic Risk</div> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> Dust Generation/ Vapor Generation Factors (<math>\mu\text{g}/\text{m}^3 \times \text{kg}/\text{mg}</math>) </div> <div style="text-align: center;"> x Unit Risk Factor (<math>\mu\text{g}/\text{m}^3</math>)<sup>-1</sup> </div> </div>
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The final equations, including all dust/vapor generation factors are presented in the text in Tables 5-7 (inhalation of contaminated soil) and Table 5-10 (inhalation of vapors).

## E.2 Models Based on Noncarcinogenic Risk

The models for determining soil concentrations for all of the site contaminants based on noncarcinogenic risk were also derived for each exposure route (with the exceptions of the inhalation of airborne contaminated soil and the inhalation of vapors) from two general equations, one for calculating the hazard quotient, and the other for determining estimated daily intake. The equation for calculating the hazard quotient is the same for each exposure route (EPA, 1989d):

(E-7) Hazard Quotient	=	<div style="text-align: center;">Estimated Daily Intake (mg/kg/day)</div> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/> <div style="text-align: center;">Reference Dose (mg/kg/day)</div>
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The equation for determining estimated daily intake is the same as that presented in Subsection E.1, equation (E-2).

The models for determining soil concentrations based on noncarcinogenic risk were derived by substituting equation (E-2) in

equation (E-7) and solving for "Contaminant Concentration in Soil." This yields the general equation:

$$(E-8) \quad \begin{array}{c} \text{Contaminant} \\ \text{Concentration} \\ \text{in Soil} \\ \text{(mg/kg)} \end{array} = \begin{array}{c} \text{Hazard} \\ \text{Quotient} \end{array} \times \begin{array}{c} \text{Reference} \\ \text{Dose} \\ \text{(mg/kg/day)} \end{array} \times \begin{array}{c} \text{Body} \\ \text{Weight} \\ \text{(kg)} \end{array}$$


---


$$\text{Route-Specific Exposure Factors} \text{ (kg/day)}^1$$

The route-specific exposure factors are presented in Table E-1. The final equations are presented in the text in Tables 5-14, 5-16 and 5-19 for the incidental soil ingestion, vegetable ingestion, and dermal contact with soil exposure routes, respectively.

For the inhalation of contaminated soil and inhalation of vapors exposure routes, the model for determining soil concentrations based on noncarcinogenic risk was derived from three equations, one for determining the hazard quotient, one for determining the estimated daily intake, and one for determining the contaminant concentration in air based on fugitive dust/vapor emissions:

$$(E-9) \quad \begin{array}{c} \text{Hazard} \\ \text{Quotient} \end{array} = \frac{\begin{array}{c} \text{Estimated Daily Intake} \\ \text{(mg/kg/day)} \end{array}}{\begin{array}{c} \text{Reference Dose} \\ \text{(mg/kg/day)} \end{array}}$$

---

<sup>1</sup> Net unit based on all route-specific exposure factors combined.

$$\begin{array}{rclcl}
 \text{(E-10)} & \text{Estimated Daily} & & \text{Air} & \text{Inhalation} \\
 & \text{Intake} & = & \text{Concentration} & \times \text{Rate} \\
 & \text{(mg/kg/day)} & & \text{of Contaminant} & \text{(m}^3\text{/day)} \\
 & & & \text{(mg/m}^3\text{)} & \\
 & & & \hline
 & & & \text{Body Weight} \\
 & & & \text{(kg)}
 \end{array}$$

$$\begin{array}{rclcl}
 \text{(E-11)} & \text{Air Concentration} & & \text{Contaminant} & \text{Dust/Vapor} \\
 & \text{of Contaminant} & = & \text{Concentration} & \times \text{Generation} \\
 & \text{(mg/m}^3\text{)} & & \text{in Soil} & \text{Factors} \\
 & & & \text{(mg/kg)} & \text{(kg/m}^3\text{)}^1
 \end{array}$$

By substituting equation (E-11) in (E-10) then substituting equation (E-10) in equation (E-9) and solving for "Contaminant Concentration in Soil", the following equation was obtained:

$$\begin{array}{rclcl}
 \text{(E-12)} & \text{Contaminant} & \text{Reference Dose} & \text{Hazard} & \text{Body Weight} \\
 & \text{Concentration} = & \text{(mg/kg/day)} & \times \text{Quotient} & \times \text{(kg)} \\
 & \text{in Soil} & & & \\
 & \text{(mg/kg)} & \hline
 & & \text{Inhalation Rate} & \text{Dust/Vapor Generation} \\
 & & \text{(m}^3\text{/day)} & \times \text{Factors} \\
 & & & \text{(kg/m}^3\text{)}
 \end{array}$$

The dust and vapor generation factors are presented in Tables E-2 and E-3, respectively. The final equations, including the dust/vapor generation factors are presented in the text in Table 5-20 (inhalation of contaminated soil) and Table 5-22 (inhalation of vapors), respectively.

<sup>1</sup> Net units based on all dust generation factors and unit conversion factors combined.



APPENDIX F

**APPROACHES TO DETERMINING ROOT UPTAKE  
FACTORS FOR ROOT VEGETABLES**

This appendix presents a discussion of the approaches used in estimating root uptake factors (RUFs) for root vegetables. The root uptake factor is defined as follows:

$$\text{RUF} = \frac{C_{\text{root}}}{C_{\text{soil}}}$$

where,

$C_{\text{root}}$  = Chemical concentration in the root

$C_{\text{soil}}$  = Chemical concentration in the soil

**F.1 Organics**

An equation for estimating RUFs for organics was derived using separate equations which related the concentration of a chemical in roots ( $C_{\text{root}}$ ) to the chemical concentration in water ( $C_{\text{water}}$ ) and the chemical concentration in water to the chemical concentration in soil ( $C_{\text{soil}}$ ).

$$(F-1) \text{ RUF} = \frac{C_{\text{root}}}{C_{\text{soil}}} = \frac{C_{\text{root}}}{C_{\text{water}}} \times \frac{C_{\text{water}}}{C_{\text{soil}}}$$

The ratio of  $C_{\text{root}}$  to  $C_{\text{water}}$  has been defined as the root concentration factor (RCF) (Briggs et al., 1982). The ratio of  $C_{\text{water}}$  to  $C_{\text{soil}}$  is expressed by the following water/soil partition model:

$$(F-2) \quad \frac{C_{\text{water}}}{C_{\text{soil}}} = \frac{1}{K_{\text{oc}} \times f_{\text{oc}}}$$

where,

$K_{\text{oc}}$  = Organic carbon partition coefficient for the chemical.

$f_{\text{oc}}$  = Fraction of organic carbon in the soil.

Substituting "RCF" and equation (H-2) for  $C_{\text{root}}/C_{\text{water}}$  and  $C_{\text{water}}/C_{\text{soil}}$ , respectively, in equation (F-1), the following equation was derived for estimating RUFs for organic chemicals.

$$(F-3) \quad \text{RUF} = \frac{\text{RCF}}{K_{\text{oc}} \times f_{\text{oc}}}$$

RCFs were calculated using an equation developed by Briggs et al. (1982). Briggs studied the uptake of organic chemicals from solution by barley shoots and established the following relationship between the root concentration factor (RCF) and the  $K_{\text{ow}}$  (octanol/water partition coefficient) for the organics tested:

$$(F-4) \quad \log (\text{RCF} - 0.82) = 0.77 \log K_{\text{ow}} - 1.52$$

The  $K_{oc}$ s and the  $K_{ow}$ s that were used in deriving the RCFs are presented in Table F-1. An  $f_{oc}$  of 0.025, which is typical of the types of soils found on site, was used (USDA, 1980). The RUFs that were estimated for the organic site contaminants are presented in Table F-2.

## F.2 Inorganics

The RUFs that were used for the metals were based on transfer coefficients that were developed by Baes et al. (1984) for tuber crops. Tubers are similar to carrots in that most tubers grow underground and serve as food storage organs. The RUFs for the metals are presented in Table F-2.

RUFs were not available for cyanide, sulfate, and nitrate. In the absence of an RUF for nitrate, the transfer coefficient for nitrogen was used (Baes et al., 1984). The inorganic nitrogen in most arable soils is nearly all used by plants in the form of nitrate (Bartholomew and Clark, 1965). There was no information in the surveyed literature from which root uptake factors for sulfate or cyanide could be determined. The transfer coefficient for sulfur was, therefore, used for sulfate and the highest (i.e., most conservative) transfer coefficient that was available for an inorganic (i.e., the transfer coefficient for chlorine) was used, by default, for cyanide (Baes et al., 1984). The uncertainty associated with using this approach is not known. However, because root uptake is a function of solubility, and because the cyanide complexes that might be found at this site are very soluble (e.g., potassium cyanide with a water solubility of  $5.0E+00$  mg/l), this conservative approach was felt to be appropriate.

Because the transfer coefficients were based on dry weight concentrations, they were adjusted for a moisture content of 88.2 percent (based on carrots) (Baes et al., 1984).

Table F-1

Organic Carbon Partition Coefficients ( $K_{OC}$ ) and  
Log Octanol/Water Partition Coefficients ( $\log K_{OW}$ )  
for the Organic Site Contaminants

Chemical	$K_{OC}$ <sup>1</sup>	$\log K_{OW}$ <sup>1</sup>
Acetone	2.20E+00	-2.40E-01
Bis(2-ethylhexyl)phthalate	3.69E+04 <sup>2</sup>	4.88E+00 <sup>3</sup>
2-Butanone	4.50E+00	2.60E-01
Carbon tetrachloride	1.10E+02	2.64E+00
Chloroform	3.10E+01	1.97E+00
1,1-Dichloroethane	3.00E+01	1.79E+00
1,2-Dichloroethane	1.40E+01	1.48E+00
1,1-Dichloroethene	6.50E+01	1.84E+00
Ethylbenzene	1.10E+03	3.15E+00
Methylene chloride	8.80E+00	1.30E+00
PAHs (as benzo(a)pyrene)	5.50E+06	6.06E+00
Tetrachloroethene	3.64E+02	2.60E+00
Toluene	3.00E+02	2.73E+00
1,1,1-Trichloroethane	1.52E+02	2.50E+00
1,1,2-Trichloroethane	5.60E+01	2.47E+00
Trichloroethene	1.26E+02	2.38E+00
Vinyl chloride	5.70E+01	1.38E+00

<sup>1</sup>Unless otherwise indicated the source of the value is EPA, 1986c.

<sup>2</sup>Estimated using the following equation:  $\log K_{OC} = 0.937 \log K_{OW} - 0.006$  (Lyman et al., 1982).

<sup>3</sup>ATSDR, 1987.

Table F-2  
Root Uptake Factors (RUFs)

Chemical	RUF
<u>Organics</u>	
Acetone	1.53E+01
Bis(2-ethylhexyl)phthalate	1.88E-01
2-Butanone	7.71E+00
Carbon tetrachloride	1.48E+00
Chloroform	2.34E+00
1,1-Dichloroethane	2.06E+00
1,2-Dichloroethane	3.53E+00
1,1-Dichloroethene	9.90E-01
Ethylbenzene	3.22E-01
Methylene chloride	5.10E+00
PAHs (as benzo(a)pyrene)	1.02E-02
Tetrachloroethene	4.24E-01
Toluene	6.19E-01
1,1,1-Trichloroethane	8.84E-01
1,1,1-Trichloroethane	2.31E+00
Trichloroethene	9.12E-01
Vinyl chloride	8.20E-01
<u>Inorganics</u>	
Arsenic	7.08E-04
Barium	1.77E-03
Beryllium	1.77E-04
Cadmium	1.77E-02
Chromium	5.31E-04
Cyanide	8.26E+00 <sup>1</sup>
Iron	1.18E-04
Lead	1.06E-03
Lithium	4.72E-04
Mercury	2.36E-02
Nickel	7.08E-03
Nitrate-Nitrite (as nitrogen)	3.54E+00
Selenium	2.95E-03
Strontium	2.95E-02
Sulfate (as sulfur)	1.77E-01
Thallium	4.72E-05
Uranium	4.72E-04
Vanadium	3.54E-04

<sup>1</sup>The root uptake factor for chlorine was used by default (see Subsection F.2)

## APPENDIX G

### METHODOLOGY USED TO DETERMINE THE PM<sub>10</sub> EMISSION FACTOR

The PM<sub>10</sub> emission factor is one of the input parameters that is used in determining soil concentrations based on the inhalation of contaminated soils (see text, Tables 5-7 and 5-20). The term PM<sub>10</sub> refers to airborne particles of respirable size (i.e., particles of 10 um or less in aerodynamic diameter). The PM<sub>10</sub> emission factor is the annual average PM<sub>10</sub> emission rate per unit area of contaminated surface. The PM<sub>10</sub> emission factor was calculated according to U.S. EPA guidance (EPA, 1985b) using the following equation:

$$(G-1) \text{ PM}_{10} \text{ Emission Factor} = \text{(mg/m}^2\text{/hr)}$$

$$\frac{0.83 \quad (1-\text{Fraction of Site Covered with Vegetation}) \quad \times \quad \text{Erosion Potential (g/m}^2\text{)} \quad \times \quad \text{Frequency of Disturbance per Month}}{(\text{Precipitation Evaporation Index}/50)^2}$$

The value of 0.83 is an empirical number that has been determined from data from field measurements. The fraction of the site covered with vegetation was assumed to be 0.25. Because the evaluation is based on a residential housing development scenario, this assumption is likely to be conservative. In a suburban residential setting, most of the soil (i.e., greater than 0.25) would be expected to be covered by buildings, vegetation, or paving, minimizing the potential for dust generation. The frequency of disturbance is assumed to be 30 times per month. The precipitation evaporation (P-E) index is a value that has been calculated by the U.S. EPA for specific regions of the country for use in equation G-1. The P-E index for the Denver area is 38 (EPA, 1985b).

The erosion potential, the quantity of erodible particles (of a given size) that is present on the surface prior to the onset of wind erosion, was calculated using equation (G-2).

$$(G-2) \quad \begin{array}{l} \text{Erosion} \\ \text{Potential} \\ (g/m^2) \end{array} = 6.7 \begin{array}{l} \text{(Fastest Mile Between - Threshold Velocity)} \\ \text{Disturbances} \\ (m/s) \end{array}$$

In the absence of site-specific observed fastest mile data (Busby, 1990), a probable value of the mean annual fastest mile for the Denver area (22 m/s) was used (EPA, 1985b). The threshold velocity was calculated using equation (G-3).

$$(G-3) \quad \begin{array}{l} \text{Threshold} \\ \text{Velocity} \\ \text{at 7 m Height} \\ (m/s) \end{array} = \begin{array}{l} \text{Ratio of the Wind} \\ \text{Speed at 7 m Height} \\ \text{to the Friction} \\ \text{Velocity} \end{array} \times \begin{array}{l} \text{Wind Erosion} \\ \text{Threshold Friction} \\ \text{Velocity (cm/s)} \end{array}$$


---

100 (cm/m)

A conservative wind erosion threshold friction velocity of 25 cm/s was assumed based on a particle size distribution mode of 100  $\mu$ m, the maximum in the EPA reference (EPA, 1985b). The ratio of the wind speed to the friction velocity was calculated using equation (G-4).

$$(G-4) \quad \begin{array}{l} \text{Ratio of the Wind} \\ \text{Speed at 7 m Height to} \\ \text{the Friction Velocity} \end{array} = \frac{1}{0.4} \ln \frac{7 \text{ (m)}}{\text{roughness height (m)}}$$

A roughness height of 5 cm was used based on a suburban residential dwelling (EPA, 1985b).

Using the equations and input factors that have been presented in this appendix, a  $PM_{10}$  emission factor of  $4,097 \text{ mg/m}^2/\text{hour}$  was calculated.



## APPENDIX H

### METHODOLOGY USED TO DETERMINE THE FRACTION OF CONTAMINANT RELEASED TO THE AIR THROUGH VOLATILIZATION ( $F_a$ )

This appendix presents the approach that was to determine  $F_a$ , the fraction of contaminant released to the air after 70 years.  $F_a$  is an input parameter in the models that are used to determine soil concentrations based on the inhalation of vapors (see text, Tables 5-7 and 5-10).

The method for calculating  $F_a$  for a specific compound is dependent on the product of the modified volatilization constant ( $K_d$ ) and the time constant for biological decay ( $t_b$ ).

If  $K_d t_b \geq 0.62$ , then

$$(H-1) \quad F_a = \frac{0.811 K_d t_b}{(K_d t_b + 1)} + 0.1878;$$

If  $K_d t_b < 0.62$ , then

$$(H-2) \quad F_a = (K_{eq} D_e t_b / l^2)^{1/2}$$

where  $K_{eq}$  is the equilibrium coefficient, and  $l$  is the depth of contaminated soil.

The time constant for biological decay ( $t_b$ ) is dependent on the biorate ( $B$ ), the time required for the compound to degrade:

$$(H-3) \quad t_b = \frac{4.83 \times 10^7}{B}$$

The biorate (B) is compound specific. Biorate values were obtained from the U.S. EPA (EPA, 1987b).

The modified volatilization constant ( $K_d$ ) is based on the volatilization constant:

$$(H-4) \quad K_d = \frac{(3.14)^2}{4} K_v$$

The volatilization constant ( $K_v$ ) reflects the rate at which the compound evaporates into the air. It is calculated from the equilibrium coefficient ( $K_{eq}$ ) and the effective diffusion coefficient ( $D_e$ ) of the compound in the soil, and from the depth of soil contaminated (l):

$$(H-5) \quad K_v = \frac{K_{eq} D_e}{l^2}$$

$D_e$  and  $K_{eq}$  were calculated from equations (H-6) and (H-7), respectively. The depth of soil contamination was assumed to be 121 cm.

The effective diffusion coefficient ( $D_e$ ), which is dependent on the compound diffusing within air pockets in the soil, was calculated based on the diffusion coefficient in air ( $D_a$ ), the soil air-filled porosity ( $E_a$ ), and the soil total porosity of waste ( $E_T$ ).

$$(H-6) \quad D_e = D_a \frac{E_a^{10/3}}{E_T^2}$$

In the absence of site-specific data or data from which to calculate site-specific values, default values given in the

model were used for the soil air-filled porosity ( $E_a$ ) and the soil total porosity of waste ( $E_T$ ). Values of 50 percent and 60.7 percent were assumed for  $E_a$  and  $E_T$ , respectively (EPA, 1987b).

The equilibrium coefficient ( $K_{eq}$ ) was calculated based on the vapor pressure of the compound ( $P^*$ ), the molecular weight of the oil ( $MW_{oil}$ ), the ideal gas constant ( $R$ ), the temperature of the vapor in soil ( $T$ ), the organic waste loading in soil ( $L$ ), and the soil air-filled porosity ( $E_a$ ).

$$(H-7) \quad K_{eq} = \frac{\frac{P^*}{\text{atm.}} \times MW_{oil} \times E_a}{RT \quad L}$$

The vapor pressure ( $P^*$ ) for each compound was obtained from the U.S. EPA (EPA, 1987b). In the absence of site-specific data or data from which to calculate site-specific values, default values given in the model were used for the molecular weight of the oil ( $MW_{oil}$ ), the soil air-filled porosity ( $E_a$ ), and the temperature of the vapor in soil ( $T$ ). Values of 282, 50 percent, and 298°K were used for  $MW_{oil}$ ,  $E_a$ , and  $T$ , respectively. The ideal gas constant is 82.1 (atm x cm<sup>3</sup>)/(g mol x deg K).

The organic waste loading in the soil ( $L$ ) was calculated based on the total waste applied to the land ( $W$ ), the fraction by weight of the applied waste that is organic ( $f_{oil}$ ), the area of soil contamination ( $A$ ), and the depth of contamination ( $l$ )

$$L = \frac{W \times f_{oil}}{A \times 10,000 \text{ cm}^2/\text{m}^2 \times l}$$

In the absence of site-specific data or data from which to calculate a site-specific value, a default value of 1,800,000 g was used for the total waste applied to the land ( $W$ ). The area

of soil contamination (A) and the depth of contamination (1) were estimated to be 25,086 m<sup>2</sup> and 121 cm, respectively. Based on the types of organic compounds that were reported in site-related media, the assumptions were made that the type of waste is oily and the fraction by weight of the applied waste that is organic ( $f_{oil}$ ) is 0.75.

The  $F_a$  for each of the contaminants that were evaluated for the inhalation of vapors exposure route and the compound-specific variables that were used to calculate  $F_a$ , are presented in Table H-1.

**TABLE H-1**  
**COMPOUND-SPECIFIC VARIABLES**  
**USED TO CALCULATE THE FRACTION OF CONTAMINANT**  
**RELEASED TO THE AIR THROUGH VOLATILIZATION**

COMPOUNDS	VAPOR PRESSURE (P*) (mm Hg)	DIFFUSION COEFFICIENT IN AIR (D(a)) (cm <sup>2</sup> /s)	BIORATE (B) (mg VO/g*hr)	EFFECTIVE DIFFUSION			MODIFIED TIME CONSTANT FOR BIOLOGICAL DECAY (T(b)) (1/s)	VERY LONG-TERM FRACTION AIR EMISSIONS (F(e))
				EQUILIBRIUM COEFFICIENT (K(eq))	COEFFICIENT IN SOIL (D(s)) (cm <sup>2</sup> /s)	VOLATILIZATION CONSTANT (K(v)) (1/s)		
Acetone	2.66E+02	1.24E-01	14.5	4.54E+01	3.34E-02	1.03E-04	2.55E-04	3.32E+06
Bis(2-ethylhexyl)phthalate	2.00E-07	3.51E-02	40.0	3.41E-08	9.45E-03	2.20E-14	5.43E-14	1.21E+06
Methyl Ethyl Ketone	1.00E+02	8.08E-02	73.8	1.71E+01	2.18E-02	2.53E-05	6.25E-05	6.55E+05
Carbon Tetrachloride	1.13E+02	8.08E-02	40.0	1.93E+01	2.18E-02	2.86E-05	7.06E-05	1.21E+06
Chloroform	2.08E+02	1.04E-01	2.9	3.55E+01	2.80E-02	6.78E-05	1.67E-04	1.64E+07
1,1-Dichloroethane	2.34E+02	1.04E-01 (1)	40.0	3.99E+01	2.80E-02	7.63E-05	1.88E-04	1.21E+06
1,2-Dichloroethane	8.20E+01	1.04E-01	32.0	1.40E+01	2.80E-02	2.67E-05	6.60E-05	1.51E+06
1,1,1-Trichloroethane	6.30E+02	1.04E-01 (1)	40.0	1.07E+02	2.80E-02	2.05E-04	5.07E-04	1.21E+06
Ethylbenzene	1.00E+01	7.50E-02	46.4	1.71E+00	2.02E-02	2.35E-06	5.80E-06	1.04E+06
Methylene Chloride	4.38E+02	1.04E-01	22.0	7.47E+01	2.80E-02	1.43E-04	3.52E-04	2.20E+06
PAHs (as Benzo(a)pyrene)	5.68E-04	4.30E-02 (2)	40.0	9.68E-05	1.16E-02	7.66E-11	1.89E-10	1.21E+06
Tetrachloroethane	1.86E+01	7.20E-02	40.0	3.17E+00	1.94E-02	4.20E-06	1.04E-05	1.21E+06
Toluene	3.00E+01	8.70E-02	73.5	5.12E+00	2.34E-02	8.18E-06	2.02E-05	6.57E+05
1,1,1-Trichloroethane	1.23E+02	7.80E-02	40.0	2.10E+01	2.10E-02	3.01E-05	7.42E-05	1.21E+06
1,1,2-Trichloroethane	2.50E+01	7.80E-02	40.0	4.26E+00	2.10E-02	6.11E-06	1.51E-05	1.21E+06
Trichloroethane	7.50E+01	7.90E-02	40.0	1.28E+01	2.13E-02	1.86E-05	4.58E-05	1.21E+06
Vinyl Chloride	2.66E+03	1.06E-01	40.0	4.54E+02	2.85E-02	8.84E-04	2.18E-03	1.21E+06
								9.98E-01
								1.63E-04
								9.79E-01
								9.89E-01
								9.99E-01
								9.95E-01
								9.91E-01
								9.97E-01
								8.84E-01
								9.98E-01
								9.62E-03
								9.39E-01
								9.42E-01
								9.90E-01
								9.57E-01
								9.84E-01
								9.98E-01

(1) Diffusion coefficient was unavailable. Value for 1,2-Dichloroethane was used.

(2) Diffusion coefficient was used for carcinogenic and noncarcinogenic PAHs.